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SHIPOP2: An Updated Program for Computing Ship Operability in Waves and Wind

K.A. McTaggart

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Author

McTaggart, Kevin A.

Approved by

J.L. Kennedy
Head, Warship Signatures and Safety

Approved for release by

W. Ellis
Chair/Document Review Panel

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Abstract

SHIPOP2 is an updated version of DREA's program for predicting ship operability in waves and wind. Given limiting motion and aircraft operability criteria, SHIPOP2 can compute limiting conditions for ship operability and percent time operable for a specified wave climate. SHIPOP2 is compatible with SHIPMO7, the latest version of DREA's ship motion program. New operability criteria include motion sickness incidence and the effects of ship motions on clearances between ship fixtures and projectiles launched from the ship. To increase the applicability and potential program user base, SHIPOP2 can read public domain wave climate data files and custom wave scattergram files prepared by the program user.

Résumé

SHIPOP2 est une version à jour du programme du CRDA visant à prévoir l'exploitabilité d'un navire dans la houle et le vent. Compte tenu de critères de mouvement limite et d'exploitabilité d'un aéronef, SHIPOP2 peut calculer les conditions limites d'exploitabilité d'un navire et le pourcentage du temps pendant lequel ce dernier est exploitable dans un régime de vagues donné. SHIPOP2 est compatible avec SHIPMO7, la dernière version du programme de calcul du mouvement d'un navire du CRDA. Les nouveaux critères d'exploitabilité comprennent l'incidence du mal de mouvement et les effets des mouvements d'un navire sur les tolérances à respecter entre les installations fixes de ce dernier et les projectiles lancés par celui-ci. Pour élargir l'applicabilité et la base potentielle d'utilisateurs du programme, SHIPOP2 peut lire des fichiers publics de données sur le régime des vagues et des fichiers spéciaux sur des diagrammes de dispersion des vagues préparés par l'utilisateur du programme.

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SHIPOP2: An Updated Program for Computing Ship Operability in Waves and Wind

McTaggart, Kevin A.

Defence Research Establishment Atlantic
December 2000

Executive summary

Introduction

Ship operability analysis combines ship motion predictions, wave climate data, and acceptable motion criteria to determine the percent time operable (PTO) for a ship in a given environment. Comparative studies of new designs is a common application of operability analysis. SHIPOP2 is an updated code for predicting ship operability in waves and wind.

Principal Results

SHIPOP2 has been updated to be compatible with SHIPMO7, the latest version of DREA's ship motion code. Public domain wave climate data files, which are now available for the North Atlantic, North Pacific, and the Canadian east coast, can be used. The program can also read wave scattergram files prepared by the program user. New operability criteria are available for motion sickness incidence, ship roll velocity, and motions of ship fixtures relative to launched projectiles.

Significance of Results

The upgraded SHIPOP2 program expands the utility of the SHIPMO7 code. Public domain wave climate files and the ability to read user-prepared wave scattergram files greatly increase the flexibility of the program. The updated code is no longer solely reliant on wave climate files that are proprietary to the US Navy; thus, the code can be used by third parties. The new operability criteria can be used to assess operation of systems such as decoy launchers.

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Future Plans

SHIPOP2 will be used for future operability studies, such as for comparison of alternative ship designs for a specified role. Another likely application is the determination of limiting sea states for operations such as replenishment-at-sea and firing of projectiles. Such analyses can be used to determine suitable locations for onboard systems. DREA intends to actively support maintenance of the SHIPOP2 code.

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SHIPOP2 : Programme à jour de calcul de l'exploitabilité d'un navire dans la houle et le vent

McTaggart, Kevin A.

Centre de Recherches pour la Défense Atlantique
Décembre 2000

Sommaire

Introduction

Dans toute analyse de l'exploitabilité d'un navire, on combine des prévisions du mouvement du navire, des données sur le régime des vagues et des critères de mouvement acceptables pour déterminer le pourcentage de temps d'exploitabilité (PTE) d'un navire dans un environnement donné. On utilise souvent ce type d'analyse pour comparer de nouveaux modèles. SHIPOP2 est un programme à jour de prévision de l'exploitabilité d'un navire dans la houle et le vent.

Principaux résultats

SHIPOP2 a été mis à jour pour être compatible avec SHIPMO7, la dernière version du programme de calcul du mouvement d'un navire du CRDA. Des fichiers publics de données sur le régime des vagues, qui sont maintenant disponibles pour l'Atlantique nord, le Pacifique nord et la Côte est du Canada, peuvent être utilisés. Le programme peut également lire des fichiers de diagrammes de dispersion des vagues préparés par l'utilisateur du programme. De nouveaux critères d'exploitabilité sont proposés pour l'incidence du mal de mouvement, la vitesse de roulis du navire et les mouvements des installations fixes du navire par rapport aux projectiles lancés.

Utilité des résultats

La version à jour du programme SHIPOP2 rend d'autant plus utile le programme SHIPMO7. L'utilisation de fichiers publics sur le régime des vagues et la possibilité de lire des fichiers de diagrammes de dispersion des vagues préparés par

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l'utilisateur donnent beaucoup plus de souplesse au programme. Le nouveau programme ne repose plus uniquement sur les fichiers sur les régimes de vagues de la Marine américaine; il peut donc être utilisé par des tiers. Les nouveaux critères d'exploitabilité peuvent être utilisés pour évaluer le fonctionnement de systèmes tels des lance-leurres.

Perspectives d'avenir

SHIPOP2 sera utilisé pour de futures études d'exploitabilité, notamment pour comparer une fonction précise d'un autre modèle de navire. On pourrait aussi l'utiliser pour déterminer les états limites de la mer permettant des activités telles le ravitaillement en mer et le lancement de projectiles. Ces analyses pourront servir à déterminer où il convient d'installer les systèmes à bord d'un navire. Le CRDA entend appuyer activement les efforts de mise à jour du programme SHIPOP2.

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Notation

A	wind cross-sectional area
A_x, A_y	wind cross-sectional areas for component directions
A_w, B_w, C_w	coefficients of quadratic wind speed equation
a	motion amplitude
a_R, b_R	coefficients of quadratic RMS response equation
C_d	air drag coefficient
C_{dx}, C_{dy}	air drag coefficients for component directions
CG	centre of gravity
g	gravitational acceleration
H_{lim}	limiting significant wave height
H_{ref}	reference significant wave height
H_s	significant wave height
$H_{s,50}$	median significant wave height
$H_{s,90}$	90'th percentile significant wave height
H_2	second reference significant wave height
h	height above deck of CG of person or object
I	tipping inertia coefficient
K	tipping stiffness coefficient
k_s	slamming form factor
L	ship length between perpendiculars
LCG	longitudinal centre of gravity
MII	motion-induced interruption
R	RMS response
R_{lim}	limiting RMS response
R_{roll}	RMS roll response
RAO	response amplitude operator
RMS	root mean square
s	half stance width of person on deck
T_p	peak wave period
T_z	zero-crossing wave period
$\overline{U}_{19.5\mathrm{m}}$	mean true wind speed at 19.5 m elevation
V	ship speed
$\hat{v}$	slamming threshold velocity
x, y, z	coordinate system with origin at ship CG
x^f, y^f, z^f	coordinates of ship fixture (relative to ship CG)
x^{fl}, y^{fl}, z^{fl}	coordinates of ship fixture relative to projectile launching point
β_s	direction of wave propagation relative to ship velocity; $\beta_s = 180°$ for head seas
Δt	time for projectile to travel from launcher to vicinity of fixture
$\Delta\xi_i^{fl}$	relative displacement component i of fixture relative to projectile trajectory
η	displacement

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η_1, η_2, η_3	ship translational displacements
η_4, η_5, η_6	ship angular displacements
γ	roll correction factor
γ_a	direction of true wind (from) relative to ship velocity; $\gamma_a = 0°$ for head wind
μ_s	static coefficient of friction
ξ_i^f	displacement component i for fixture
ω	wave frequency
ω_e	wave encounter frequency

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1 Introduction

This report presents an updated version of DREA's ship operability code SHIPOP, originally presented in Reference 1. For a ship operating in a given wave climate, SHIPOP provides estimates of percent time operable (PTO), the percentage of time during which no specified operability criteria are exceeded. These estimates can be used to identify ship deficiencies and for comparing alternative ship designs.

Required input for SHIPOP includes wave and wind climate data, ship response amplitude operators (RAOs), and limiting criteria for motions and relative wind speed envelopes. SHIPOP then evaluates limiting wave conditions and percent time operable for the given operational area.

The main upgrade for the current SHIPOP version is compatibility with SHIPMO7, the latest version of DREA's strip theory code [2]. All wave data for the original SHIPOP program were proprietary to the US Navy and could not be distributed to third parties. SHIPOP2 introduces additional non-proprietary wave data files and a capability to read wave scattergrams prepared by the program user. The code also introduces roll velocity and fixture relative displacements as new operability criteria.

The following section summarizes program changes implemented for SHIPOP2. Section 3 develops the theory for operability criteria based on the motion of a ship fixture relative to a projectile launched from the ship. The preparation of program input is discussed in Section 4, which is followed by a guide for running the program in Section 5 and description of output in Section 6. Concluding remarks are given in Section 7.

2 Changes for SHIPOP2

Minimal changes have been made from the original SHIPOP code described in Reference 1. The new code is compatible with DREA's updated strip theory program SHIPMO7 [2]. To enhance portability of data across platforms, the SHIPMO7 output post-processing file has been changed from binary to ASCII, with its format described in Annex A. To ensure compatibility with SHIPMO7, SHIPOP2 checks arrays dimensions related to the number of frequencies and number of sea directions. The standard versions of both programs accommodate a maximum of 40 wave frequencies and 36 sea directions.

While the original SHIPOP program was restricted to using wave data files proprietary to the US Navy, SHIPOP2 includes additional non-proprietary wave data files and a capability to read wave scattergram files prepared by the program user. For

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annual conditions in the North Atlantic and North Pacific, SHIPOP2 has wave data files based on the public domain data of Reference 3. SHIPOP2 can also use wave climate data from Reference 4 for the east coast of Canada. If a program user wants to use wave data which are not included in SHIPOP2, then the program can read a user-prepared scattergram file based on sources such as BMT Global Wave Statistics [5]. To assist with management of wave climate data files, SHIPOP2 reads the directory for these files as program input.

The program input for SHIPOP2 is slightly different from that for the original SHIPOP program. For input options which are defined by character strings, the possible input strings no longer have spaces within them (e.g. SHIPOP2 requires input string "GRIDPOINT" instead of "GRID POINT"). The user input for wave data has been changed to reflect the expanded capabilities of the program.

For input seakeeping criteria, the program now reads descriptive labels up to 15 characters long. The program also includes new seakeeping criteria relevant to projectile launching systems. Limiting roll velocity is frequently given as a specification for launching systems. SHIPOP2 introduces new criteria for longitudinal, lateral, and vertical displacements of ship fixtures during specified time intervals. These new criteria can be used to assess whether a ship fixture, such as a mast, will move into the path of a launched projectile. SHIPOP2 also includes seakeeping criteria for motion sickness incidence, which is evaluated using the method presented by Colwell [6].

3 Displacement of Fixture Relative to Launched Projectile

When launching a projectile from a ship, the ship motions can cause a fixture such as a mast to move into the path of the projectile. This effect will be most significant for slow projectiles such as decoys, which can take a few seconds to clear the vicinity of the ship. This section describes the theory used for computing relative fixture displacements.

The analysis considers whether a fixture will move into the path of a launched projectile. Figure 1 shows the ship coordinate system used in the analysis. If the ship motions are of long period relative to the time for the projectile to travel from its launcher to the vicinity of a fixture, then the displacement of the fixture relative to the projectile trajectory can be expressed as follows:

$$\Delta\xi_i^{fl} = \dot{\eta}_5\, z^{fl}\Delta t \;-\; \dot{\eta}_6\, y^{fl}\,\Delta t \;+\; \frac{1}{2}\ddot{\xi}_i^{f}\,\Delta t^2 \qquad (1)$$

$$\Delta\xi_2^{flt} = -\dot{\eta}_4\, z^{fl}\,\Delta t \;+\; \dot{\eta}_6\, x^{fl}\,\Delta t \;+\; \frac{1}{2}\ddot{\xi}_2^{f}\,\Delta t^2 \tag{2}$$

$$\Delta\xi_3^{flt} = \dot{\eta}_4\, y^{fl}\,\Delta t \;-\; \dot{\eta}_5\, x^{fl}\,\Delta t \;+\; \frac{1}{2}\ddot{\xi}_3^{f}\,\Delta t^2 \tag{3}$$

where $\Delta\xi_i^{flt}$ is the relative displacement for direction i of the fixture relative to the decoy trajectory path, $\dot{\eta}_j$ is the ship angular velocity for direction j, x^{fl}, y^{fl}, z^{fl} are the coordinates of the ship fixture relative to the projectile launcher, Δt is the time required for the projectile to travel from its launcher to the vicinity of the fixture, and $\ddot{\xi}_i^{f}$ is the acceleration of the fixture for direction i. For computations in the frequency domain using the convention $\eta(t) = Real\,\{\eta\, e^{i\omega_e t}\}$, the above equations can be re-written as:

$$\Delta\xi_1^{flt} = i\,\omega_e\,\Delta t\,\eta_5\, z^{fl} \;-\; i\,\omega_e\,\Delta t\,\eta_6\, y^{fl} \;-\; \frac{1}{2}\omega_e^2\,\Delta t^2\,(\eta_1 + \eta_5 z_f - \eta_6 y_f) \tag{4}$$

$$\Delta\xi_2^{flt} = -i\,\omega_e\,\Delta t\,\eta_4\, z^{fl} \;+\; i\,\omega_e\,\Delta t\,\eta_6\, x^{fl} \;-\; \frac{1}{2}\omega_e^2\,\Delta t^2\,(\eta_2 - \eta_4 z_f + \eta_6 x_f) \tag{5}$$

$$\Delta\xi_3^{flt} = i\,\omega_e\,\Delta t\,\eta_4\, y^{fl} \;-\; i\,\omega_e\,\Delta t\,\eta_5\, x^{fl} \;-\; \frac{1}{2}\omega_e^2\,\Delta t^2\,(\eta_3 + \eta_4 y_f - \eta_5 x_f) \tag{6}$$

where ω_e is wave encounter frequency and η_i is the complex motion amplitude for mode i.

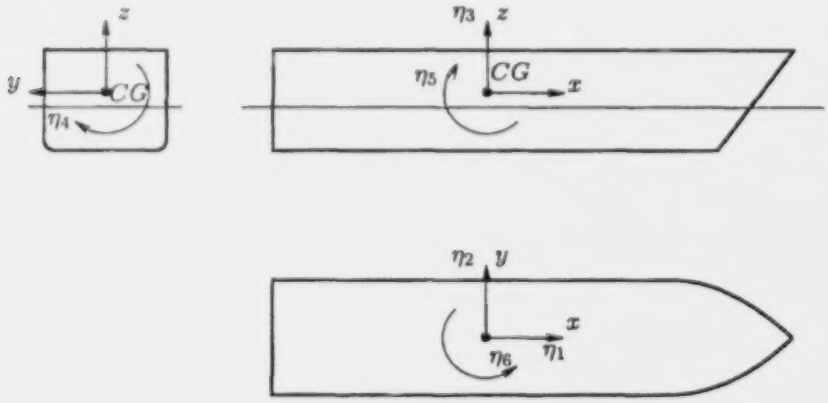

Figure 1: SHIPOP2 Axis System

The equations presented thus far assume that the ship velocity and acceleration are approximately constant during time Δt (i.e. $\omega_e \Delta t$ is small). If time Δt is not small relative to the period of ship motions, then computations of quantities ξ_i^{flt} will

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have to consider limits on displacements during a given wave cycle. For a simple harmonic process $\eta = a \sin \omega_e t$, the occurrence of maximum velocity when $\omega_e t = 0$ and displacement $\eta = 0$ will be followed by a maximum displacement of $\eta = a$ when $\omega_e t = \pi/2$. Alternatively, the occurrence of maximum acceleration when $\omega_e t = -1/2\pi$ and $\eta = -a$ will be followed by a change of $2a$ in displacement to give $\eta = a$ when $\omega_e t = \pi/2$. These limits on displacement due to small ship motion period can be incorporated in an approximate manner as follows:

$$\Delta\xi_1^{fl} = i \min(\omega_e \Delta t, 1)\, \eta_5\, z^{fl} - i \min(\omega_e \Delta t, 1) \eta_6\, y^{fl} - \frac{1}{2} \min(\omega_e^2 \Delta t^2, 4)\, (\eta_1 + \eta_5 z_f - \eta_6 y_f) \tag{7}$$

$$\Delta\xi_2^{fl} = -i \min(\omega_e \Delta t, 1)\, \eta_4\, z^{fl} + i \min(\omega_e \Delta t, 1)\, \eta_6\, x^{fl} - \frac{1}{2} \min(\omega_e^2 \Delta t^2, 4)\, (\eta_2 - \eta_4 z_f + \eta_6 x_f) \tag{8}$$

$$\Delta\xi_3^{fl} = i \min(\omega_e \Delta t, 1)\, \eta_4\, y^{fl} - i \min(\omega_e \Delta t, 1)\, \eta_5\, x^{fl} - \frac{1}{2} \min(\omega_e^2 \Delta t^2, 4)\, (\eta_3 + \eta_4 y_f - \eta_5 x_f) \tag{9}$$

Using the above equations for frequency domain analysis, SHIPOP2 computes RMS relative fixture displacements.

When using relative fixture displacements as operability criteria, it should be noted that maximum displacement is significantly greater than RMS displacement. The maximum relative displacement in a one hour seaway will be approximately four times the RMS relative displacement; thus, the limiting RMS relative displacement of a fixture should be several times greater than the clearance between the trajectory and the fixture.

4 Program Input

Annex B.1 gives a detailed description of SHIPOP2 input, and Annex B.2 gives a sample input file. This section gives background information to assist with preparation of program input. Figure 1 shows the ship coordinate system used by SHIPOP2, and Figure 2 gives the wave and wind heading conventions.

4.1 Ship Regular Wave Responses

SHIPOP2 can read regular wave ship responses from SHIPMO7 [2]. Annex A describes the new format of ASCII post-processing files from SHIPMO7. After

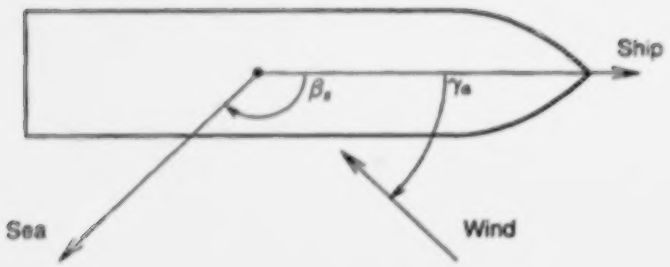

***Figure 2:** Definition of Sea and Wind Directions Relative to Ship Heading*

reading response amplitude operators (RAOs), SHIPOP2 then evaluates ship operability for the speeds and headings of the available RAOs. When using SHIPOP2 to evaluate operability for short-crested seas, the RAO file should include an adequate range of sea directions, with a maximum sea direction increment of 45 degrees. If all seakeeping criteria locations are on the ship centreline, then the sea directions should cover the range 0-180 degrees. If one or more seakeeping positions is off-centre, then additional sea directions must cover the range between 180 degrees and a maximum value between 315 and 360 degrees. The wave directions must be in consecutive order, ascending or descending.

Due to the nonlinearity of ship roll response, RAOs used for operability analysis should be generated for a sea state approximating the limiting operability conditions. For example, Sea state 5 (H_s = 3.25 m, T_p = 9.7 s) is a suitable condition for generating regular wave responses for naval frigates.

4.2 Ship Dimensions

The user provides input principal ship dimensions to SHIPOP2. These input dimensions are primarily used for computation of input seakeeping positions relative to the ship centre of gravity (CG). Input ship dimensions should be consistent with values from the input RAO file.

4.3 Nonlinear Roll Response

SHIPOP2 predicts RMS ship motions and derived responses using RAOs generated for a single reference sea state; however, SHIPOP can model roll nonlinearity using

a roll correction factor γ. The roll correction factor is a function of significant wave height and ship speed, and is equal to unity at the significant wave height for which ship RAOs have been computed:

$$\gamma = f(H_s, V) \tag{10}$$

$$\gamma(H_s, V) = 1.0 \qquad \text{for } H_s = H_{ref} \tag{11}$$

where V is ship speed and H_{ref} is the significant wave height for which the RAOs have been computed.

If the user requests nonlinear roll modelling, then SHIPOP2 requires the following values for each ship speed to evaluate the degree of roll nonlinearity:

- significant wave height H_{ref} of ship motion RAOs,
- characteristic RMS roll response in beam seas $R_{roll}(H_{ref}, V)$,
- second significant wave height H_2,
- characteristic RMS roll response in beam seas $R_{roll}(H_2, V)$.

SHIPOP2 assumes that the degree of roll nonlinearity is independent of heading and peak wave period; thus, the RMS roll responses $R_{roll}(H_{ref}, V)$ and $R_{roll}(H_2, V)$ are given for beam seas and a peak wave period where typical roll nonlinearity occurs. The relationship between the roll correction factor γ and RMS roll responses is:

$$\gamma(H_s, V) = \frac{R_{roll}(H_s) \;/\; H_s}{R_{roll}(H_{ref}) \;/\; H_{ref}} \tag{12}$$

Computed nonlinear roll responses for the frigate of Reference 1 verify that a roll correction factor derived in beam seas can adequately model the roll nonlinearity at other headings and wave periods. For accurate modelling of ship operability, the reference significant wave height should be selected such that it would be representative of limiting wave conditions, thus limiting the degree of required roll correction. SHIPOP2 assumes that roll nonlinearity is independent of frequency. Because of the importance of roll damping for resonance conditions, input reference roll responses should be specified for a peak wave period near the ship roll resonance period.

After reading ship motion RAOs (and characteristic RMS roll response values if roll nonlinearity is being modelled), SHIPOP2 computes RMS responses relevant to the motion criteria for all ship speeds, headings, and peak wave periods. These RMS motions are computed for the reference wave height H_{ref}, and for wave height H_2

if roll nonlinearity is being modelled. For computing RMS motions at wave height H_2, roll RAOs are modified as follows:

$$\eta_4(H_2, V, \beta_s, \omega) = \eta_4(H_{ref}, V, \beta_s, \omega) \frac{R_{roll}(H_2, V)}{R_{roll}(H_{ref}, V)} \frac{H_{ref}}{H_2} \tag{13}$$

where η_4 is the complex roll RAO, β_s is direction of wave propagation, and ω is wave frequency. The computed RMS motions for wave height H_{ref}, and for wave height H_2 if roll nonlinearity is being modelled, are used to evaluate limiting significant wave heights based on motion criteria.

The exponential response model describes the variation of RMS response with significant wave height as follows:

$$R(H_s) = R(H_{ref}) \left(\frac{H_s}{H_{ref}}\right)^{1-\alpha} \tag{14}$$

The exponent α for roll is typically in the range $0.0 \leq \alpha \leq 0.20$ and is evaluated for a given ship speed from:

$$\alpha(V) = 1.0 - \frac{\ln[R_{roll}(H_2, V)/R_{roll}(H_{ref}, V)]}{\ln[H_2/H_{ref}]} \tag{15}$$

The correction equation for roll RAOs at a given wave height is:

$$\eta_4(H_s, V, \beta_s, \omega) = \eta_4(H_{ref}, V, \beta_s, \omega) \left[\frac{H_s}{H_{ref}}\right]^{-\alpha(V)} \tag{16}$$

4.4 Wave Climate Data

SHIPOP2 can read wave climate data from a variety of sources, including user wave scattergram files. SHIPOP2 has its own wave data files for the North Atlantic, North Pacific, and east coast of Canada.

The wave climate data files for the east coast of Canada are based on a wind and wave climate atlas developed by MacLaren Plansearch [4]. Figure D.1 in Annex D.1 shows Canadian Atlantic areas for which wave climate data are available. Table D.1 gives nominal locations for the Canadian Atlantic wave climate areas, and Table D.2 gives wave and wind climate parameters for the CANLANT area.

The wave climate data for the North Atlantic and North Pacific have been generated by the Spectral Ocean Wave Model (SOWM), as described in References 3, 7, 8, and 9. The wave climate data are based upon historical measured barometric pressure fields and numerically modelled wind and resulting waves. The data

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files give joint probability distributions of peak wave period and significant wave height. These probability distributions are tabulated for the general North Atlantic and North Pacific, and for grid points given in Tables D.3 and D.4 and Figures D.2 and D.3 in Annex D.2 and D.3. The majority of the SOWM wave climate data files are proprietary to the US Navy; thus, DREA cannot distribute the files to parties outside of DND. For SHIPOP2 users outside of DND, public domain wave climate files have been developed for annual conditions in the North Atlantic and North Pacific general operational areas. These data files are based on SOWM results presented in Reference 3.

4.5 Ship Headings

Input ship headings for SHIPOP2 are determined by the the RAO file generated by SHIPMO7. The range of RAO headings required by SHIPOP2 depends on user input. If any seakeeping position is off-centre or if the relative wind aircraft operability envelope is asymmetrical, then the ship RAO file should include headings greater than 180 degrees. If operability in short-crested seas is being evaluated, then the RAO headings should span 0-180 degrees for a symmetrical case, and 0 to a minimum of 315 degrees for an asymmetrical case. The maximum heading increment for a short-crested seas calculation should be 45 degrees. If the user input file specifies heading weights, then the headings must equal those in the RAO file.

4.6 Wind Conditions

Limiting wind envelopes for air operations are dependent on wind conditions. In addition, wind forces can affect motion-induced interruptions. SHIPOP2 assumes collinear wind and wave directions. SHIPOP2 models wind speed as a function of significant wave height as follows:

$$\overline{U}_{19.5\mathrm{m}} = A_w H_s^2 + B_w H_s + C_w \qquad (17)$$

where $\overline{U}_{19.5\mathrm{m}}$ is mean true wind speed in knots at an elevation of 19.5 m, A_w, B_w, C_w are equation coefficients, and H_s is significant wave height. This model was selected after analysing joint probability distributions of significant wave height and wind speed for the North Atlantic. Figure 3 shows mean wind speed given significant wave height for the North Atlantic, and indicates a strong linear relationship between wind speed and wave height; thus, the complexity of a quadratic fit is not justified for the North Atlantic but could be useful for other regions. Note that the wind speeds of Figure 3 are mean values for wave height bandwidths of 0.5 m; thus, each data point is typically the mean of a large number of wind speed values. The strong correlation of significant wave height with wind speed is due to the local generation of sea by the wind; however, the presence of swell is largely uncorrelated with local wind speed.

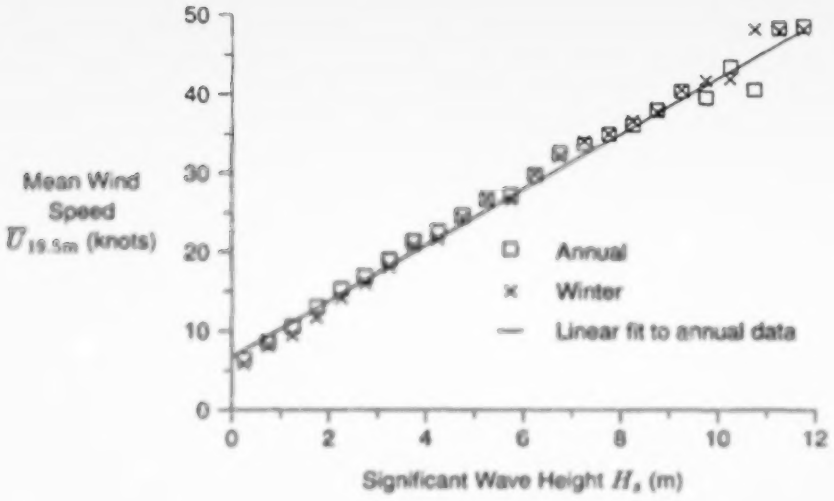

Figure 3: *Mean Wind Speed Given Significant Wave Height for the North Atlantic*

4.7 Relative Wind Operability Criteria

SHIPOP2 input can include limiting relative wind speeds for relative wind headings. Limiting relative wind envelopes are very useful for assessing the feasibility of aircraft operations such as helicopter take-offs and landings. Limiting wind envelopes will depend upon the aircraft type being considered. Figure 4 gives a qualitative representation of a limiting wind envelope for a helicopter. The shaded region of the diagram represents the region of safe wind speeds, with wind speed being proportional to radius from the centre of the diagram. Like SHIPOP2, the diagram uses a "direction from" convention for wind direction.

4.8 Motion Operability Criteria

Motion criteria are used to determine limiting conditions for ship operability. SHIPOP2 is very flexible with respect to the number of motion-related operability criteria that can be specified for a given run. In the simplest case, the user only has to specify one motion criterion. For more elaborate analyses, limits for many criteria can be specified. Criteria which vary with location onboard ship can be evaluated for a variable number of positions. For example, a single SHIPOP2 run could consider vertical acceleration at both the bridge and flight deck for a frigate.

Table 1 gives motion criteria and default values that are available in SHIPOP2. The default values are based largely upon a review of operability criteria by Smith

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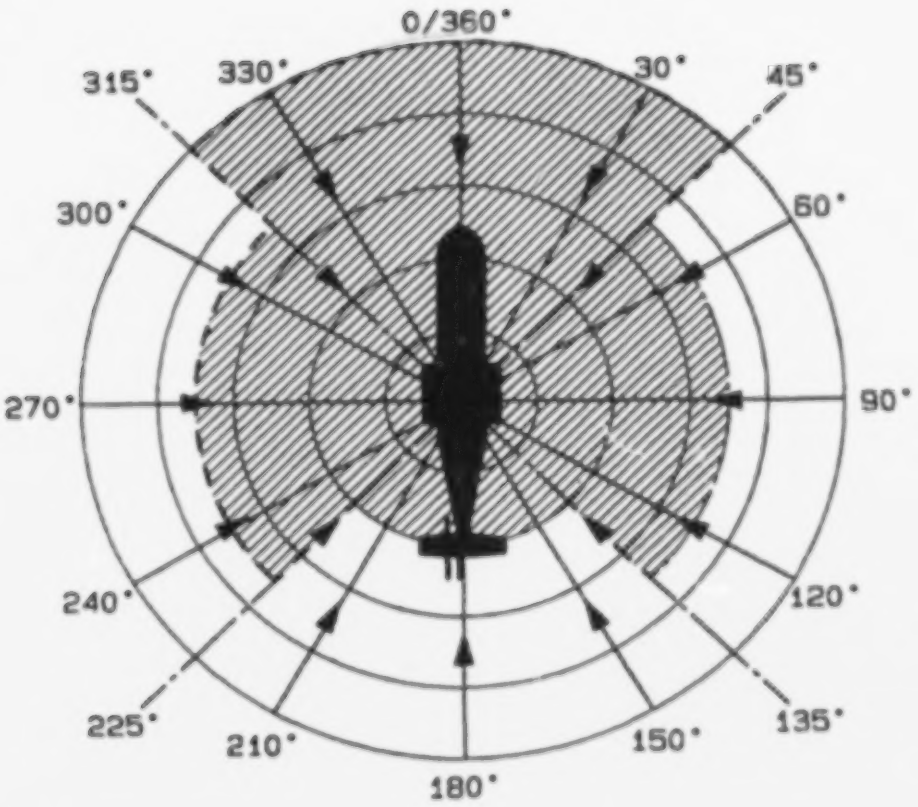

Figure 4: *Qualitative Representation of Helicopter Limiting Wind Envelope*

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and Thomas [10]. The default motion-induced interruption (MII) value of 1.5 per minute represents a serious risk level for human sliding and tipping, as described in Reference 11. For sliding and tipping of large equipment, the acceptable MII rate would be much lower. With the exception of roll and pitch, a location onboard ship must be specified for each criterion. The bridge and flight deck are often locations of interest for location-dependent criteria.

Among the various motion criteria, the evaluation of MIIs is the most complex. The incidence of tipping events for a person or object depends upon the tipping coefficient s/h, where s is the half stance width and h is the height above deck of the centre of gravity, as shown in Figure 5. The tipping coefficient is usually dependent upon the direction of tipping. To evaluate the incidence of sliding events, the tipping coefficient s/h can be replaced by the static coefficient of friction μ_s. Table 2 gives representative tipping and sliding coefficients from Reference 12 and unpublished data. The wide range of friction coefficients suggests the incidence of sliding can vary greatly, depending on sliding surface conditions. Because the static coefficient of friction for a person is usually greater than the tipping coefficient, a person will usually tip more easily than slide. Table 3, reproduced from Reference 11, gives risk levels associated with motion-induced MIIs.

***Figure 5:** Model for Person Standing on Deck*

SHIPOP2 uses the theory described in Reference 1 for including the effects of wind forces on MIIs. Table 4 gives representative values for wind drag acting on a human facing fore-aft. The original SHIPOP program used the values in Table 4 as default values; however, SHIPOP2 uses zero values as defaults for wind drag terms,

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Table 1: *SHIPOP Operability Criteria and Default Values*

Criteria	Default Value
Roll	4.0 degrees RMS
Pitch	1.5 degrees RMS
Deck wetness	30 per hour
Slamming	20 per hour
Vertical displacement	1.0 m RMS
Vertical velocity	1.0 m/s RMS
Vertical acceleration	0.20 g RMS
Relative displacement	999 ft or m RMS
Lateral acceleration	0.07 g RMS
Longitudinal acceleration	0.07 g RMS
Lateral force estimator	0.07 g RMS
Longitudinal force estimator	0.07 g RMS
Sliding MIIs	1.5 per minute
Tipping MIIs	1.5 per minute
Roll rate	999 deg/s RMS
Longitudinal relative fixture displacement	999 ft or m RMS
Lateral relative fixture displacement	999 ft or m RMS
Vertical relative fixture displacement	999 ft or m RMS
Maximum motion sickness incidence	20 percent
Motion sickness incidence	20 percent after 2 days

Table 2: *Representative Tipping and Sliding Coefficients*

Tipping in the forward direction, s/h	0.17
Tipping in the sideways direction, s/h	0.25
Sliding, person standing on dry deck, μ_s	0.7
Sliding, chair on interior floor, μ_s	0.19
Sliding, helicopter for various deck conditions, μ_s	0.2 - 0.8

Table 3: *MII Risk Levels*

Risk Level	MIIs per Minute
1. possible	0.1
2. probable	0.5
3. serious	1.5
4. severe	3.0
5. extreme	5.0

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representing the case of a person inside a ship.

***Table 4:** Representative Wind Drag Terms for a Human Facing Fore-Aft*

Longitudinal drag coefficient × area, $C_{dx}A_x$	0.78 m^2
Lateral drag coefficient × area, $C_{dy}A_y$	0.34 m^2

5 Running SHIPOP2

The SHIPOP2 program is run by starting the executable program file. Input is read from file "Shipop2.inp" and output is written to file "Shipop2.out". DREA currently supports a version for personal computers running Windows 95 or NT. The program will typically complete execution within a few seconds.

Limits on maximum values of many SHIPOP2 input variables are set by a Fortran PARAMETER statement in module PARAM, which is included in many SHIPOP2 subroutines using a Fortran USE statement. Table 5 gives parameters set in module PARAM. If a user input value exceeds the capacity of the SHIPOP2 parameters, then the program writes a descriptive error message and terminates. If the user wishes to increase the capacity of SHIPOP2, he can adjust values in module PARAM and re-compile the program.

6 Program Output

Annex C gives sample output from SHIPOP2. This section gives information for interpreting results given in the SHIPOP2 output.

6.1 Echo of User Input

The SHIPOP2 output begins with user input values. If the program has set default values, then these values are given in the program output. The echo of user input includes ship dimensions, wind options, and motion criteria.

6.2 RAO File Properties

The program gives main properties from the file from which ship RAOs are read. The speed and heading probabilities for operability computations follow the RAO file properties.

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Table 5: SHIPOP2 Maximum Parameters

Parameter	Description	Value
NHEADMAX	Number of wave headings	36
NTPMAX	Number of wave climate peak wave periods	15
NWVFREQMAX	Number of wave frequencies for RAOs	40
NHSCUMMAX	Number of wave climate sig. wave heights	49
NCRIMAX	Number of motion criteria	20
NSPMAX	Number of ship speeds	5
NCPMAX	Number of input parameters for motion criterion	14
NPOSMAX	Number of seakeeping positions in RAO file	10
NSEAWAYMAX	Number of seaways in RAO file	11
NSTLOADMAX	Number of load stations in RAO file	51

6.3 Wave and Wind Climate Summary

The wave and wind climate summary gives the location and season for the climatic data. A table gives the cumulative distribution for significant wave height, with corresponding wind speeds based on Equation (17) if applicable.

6.4 Ship Motions for Reference Wave Conditions for Ship Speed

Motion and operability output is repeated for each ship speed, beginning with representative ship motions for a reference wave condition. If roll response is nonlinear, then additional motions are given for a second wave condition.

6.5 Limiting Wave and Wind Conditions for Ship Speed

Allowable wind speeds are given based on ship speed, heading, and the limiting relative wind envelope. For each allowable wind speed range, a corresponding significant wave height range is given.

Following allowable wind speeds, limiting significant wave heights are given for all combinations of heading and peak wave period. The limiting significant wave height is the lowest wave height for which any motion criterion fails. Additional output tables give the failure criteria associated with the limiting significant wave heights. A final table of limiting significant wave heights considers the central 50, 95, and 100 percentile bands of peak wave periods given significant wave height. For each band, the limiting wave height represents the minimum value for relevant peak wave periods.

6.6 Percent Time Operable for Ship Speed

A table of percent time operable (PTO) is the final output for each ship speed. The table includes PTO values based on limiting relative wind operational envelopes and motion criteria. The output PTO values are based on the joint distribution of significant wave height and peak wave period. PTO values are also given based on weighted probabilities for all headings.

6.7 Operability for All Ship Speeds

After all output for individual ship speeds, a summary is given of operability based on all ship speeds and their weighting factors.

7 Concluding Remarks

The updated SHIPOP2 code is a companion post-processor to SHIPMO7, the latest version of DREA's strip theory code. SHIPOP2 also consolidates revisions that have been made to SHIPOP during several years.

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References

1. McTaggart, K.A. and Graham, R. (1993). SHIPOP: A Program for Computing Ship Operability in Waves and Wind. (DREA TM 93/202). Defence Research Establishment Atlantic.

2. McTaggart, K.A. (1997). SHIPMO7: An Updated Strip Theory Program for Predicting Ship Motions and Sea Loads in Waves. (DREA TM 96/243). Defence Research Establishment Atlantic.

3. Bales, S.L. (1984). Development and Application of a Deep Water Hindcast Wave and Wind Climatology. In *Royal Institute of Naval Architects Wave and Wind Climate World Wide Symposium*, London.

4. Ltd., MacLaren Plansearch (1991). Wind and Wave Climate Atlas, Volume I, The East Coast of Canada. Technical Report. Prepared for Transporation Development Centre, Transport Canada.

5. British Maritime Technology Limited (1986). Global Wave Statistics, London: Unwin Brothers.

6. Colwell, J.L. (1994). Motion Sickness Habituation in the Naval Environment. (DREA TM 94/211). Defence Research Establishment Atlantic.

7. Pierson, W.J. (1982). The Spectral Ocean Wave Model (SOWM), A Northern Hemisphere Model for Specifying and Forecasting Ocean Wave Spectra. DTNSRDC. (Report DTNSRDC/82/011).

8. Bales, S.L., Lee, W.T., and Voelker, J.M. (1981). Standardized Wave and Wind Environments for NATO Operational Areas. DTNSRDC. (Report DTNSRDC/SPD-0919-01).

9. Lee, W.T., Bales, S.L., and Sowby, S.E. (1985). Standardized Wind and Wave Environments for North Pacific Ocean Area. DTNSRDC. (Report DTNSRDC/SPD-0919-02).

10. Smith, T.C. and Thomas III, W.L. (1989). A Survey and Comparison of Criteria for Naval Missions. DTRC. (Report DTRC/SHD-1312-01).

11. Graham, R. (1990). Motion-Induced Interruptions as Ship Operability Criteria. *Naval Engineers Journal*, **102**(2), 65–71.

12. Graham, R., Baitis, A.E., and Meyers, W.G. (1992). On the Development of Seakeeping Criteria. *Naval Engineers Journal*, **104**(2), 259–275.

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13. Schmitke, R.T. (1979). Improved Slamming Predictions for the PHHS Computer Program. (DREA TM 79/A). Defence Research Establishment Atlantic.

14. McTaggart, K.A. (2000). Improved Modelling of Capsize Risk in Random Seas. (DREA TM 2000-137). Defence Research Establishment Atlantic.

Annex A
ASCII Post-Processing Output File from SHIPMO7

Version 7.2 of DREA's SHIPMO program [2] writes output post-processor files in ASCII rather than binary format. ASCII files are compatible across platforms and can be read by programs written in any computer language. SHIPMO7.2 uses Fortran 90 allocatable arrays, which greatly reduces the size of output post-processor files. For SHIPMO7.2 to write an ASCII post-processor file, input control variable OUTPPR of Record (b) must be set to OUTASCII.

Record 1 - Source Program Name
Format (A20)

PROGRAM	Char*20	Character string "SHIPMO7.2" identifying program name.

Record 2 - Title
Format (A100)

TITLE	Char*100	Run title with time and date appended.

Record 3 - Control Variables
Format (A20, 1X, A20, 1X, A20, 1X, A20)

OUTSYS	Char*20	Output units (BRITISH or METRIC).
WATERTYPE	Char*20	Water type (SALT or FRESH).
HYMETHOD	Char*20	Method for computing hydrodynamic coefficients (BOUND2D or CONFORMAL).
SPECTRUM	Char*20	Spectrum type (REGULAR, QUADRATIC, BRETSCHNEIDER, JONSWAP, OCHIHUBBLE, INPUTUNI, TENPARAMETER, ODGPHINDCAST, or INPUTDIR)

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Record 4 - Ship Dimensions
Format (F12.3, 1X, I4, 6(1X, F12.3))

SHIPLEN	Real	Ship length between perpendiculars (ft or m).
NST	Integer	Number of stations (typically 21).
DISP	Real	Ship displacement (tons or tonnes).
LCBFP	Real	Distance from forward perpendicular to LCB (ft or m).
DRAFTMID	Real	Draft at midships (ft or m).
TRIMST	Real	Trim by stern (ft or m).
KG	Real	Height of CG above baseline (ft or m).
BEAMMID	Real	Beam at midships (ft or m).

Record 5 - Physical Constants
Format (F12.3, 1X, F12.3)

WDENSITY	Real	Water density (slugs/ft^3 or kg/m^3).
GRAVITY	Real	Gravitational acceleration (ft/s^2 or m/s^2).

Record 6 - Number of Stations for Sea Load Computations
Format (I4)

NSTLOAD	Integer	Number of stations for sea load computations.

Record 7 - Stations for Sea Load Computations
Written only if NSTLOAD $\geq$ 1 in Record (6)
Format (10(F10.3, 1X))

XSTLOAD(I)	Real	Array of dimension NSTLOAD with station numbers for sea loads.

Record 8 - Number of Positions for Seakeeping Calculations
Format (I4)

NPOS	Integer	Number of positions for seakeeping computations.

Record 9 - Position Locations for Seakeeping Calculations
Written only if NPOS $\geq$ 1 in Record (8)
Format (9(F10.3, 1X))

XSTPOS(I)	Real	Array of dimension NPOS with station numbers of seakeeping positions.
YPOS(I)	Real	Array of dimension NPOS with horizontal coordinates of seakeeping positions (ft or m).
ZPOSBL(I)	Real	Array of dimension NPOS with vertical coordinates of seakeeping positions relative to baseline (ft or m).

Record 10 - Number of Ship Speeds
Format (I4)

NSPEED	Integer	Number of ship speeds.

Record 11 - Ship Speeds
Format (10(F10.3, 1X))

SPDKNOT(I)	Real	Array of dimension NSPEED with ship speeds (knots).

Record 12 - Number of Sea Directions
Format (I4)

NSEADIR	Integer	Number of sea directions.

Record 13 - Sea Directions
Format (10(F10.3, 1X))

SEADIR(I)	Real	Array of dimension NSEADIR with sea directions.

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Record 14 - Number of Seaways
Format (I4)

NSEAWAY	Integer	Number of seaways.

Record 15 - Seaways
Format (10(F10.3, 1X))

HSW(I)	Real	Array of dimension NSEAWAY with significant wave heights (ft or m).
TSW(I)	Real	Array of dimension NSEAWAY with characteristic wave periods (s).

Record 16 - Wave frequencies
Format (I4, 1X, F9.3, 1X, F9.3)

NWVFREQ	Integer	Number of wave frequencies.
WVFREQMIN	Real	Minimum wave frequency (rad/s).
DWVFREQ	Real	Wave frequency increment (rad/s).

Ship Motions and Loads in Regular and Irregular Seas for each Ship Speed

The remaining sequence of records is repeated for each ship speed. For regular seas and irregular seas with a principal wave direction, the sea direction index J in the motion and load arrays corresponds to the sea direction relative to the ship forward speed. For irregular seas without a principal wave direction (SPECTRUM = TENPARAMETER, ODGPHINDCAST, or INPUTDIR), the direction index J corresponds to the ship compass heading for the irregular responses only.

Record 17 - Label for Ship Speed
Format (A40)

SPEEDLABEL	Char*40	"Results for Following Ship Speed (knots)"

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Record 18 - Ship Speed
Format (F9.3)

SPEEDKT	Real	Ship speed (knots)

Record 19 - Label for Complex Motion RAOs in Regular Waves
Format (A36)

MOTIONRAOLABEL	Char*36	"Complex Motion RAOs in Regular Waves"

Record 20 - Complex Motions in Unit Amplitude Regular Waves for Seaway 1
Format (5('(', E12.6, ',', E12.6, ')'))

CSURGEREG(I,J)	Complex	Complex surge amplitude (ft/ft or m/m).
CSWAYREG(I,J)	Complex	Complex sway amplitude (ft/ft or m/m).
CHEAVEREG(I,J)	Complex	Complex heave amplitude (ft/ft or m/m).
CROLLREG(I,J)	Complex	Complex roll amplitude (rad/ft or rad/m).
CPITCHREG(I,J)	Complex	Complex pitch amplitude (rad/ft or rad/m).
CYAWREG(I,J)	Complex	Complex yaw amplitude (rad/ft or rad/m).
CRUDREG(I,J)	Complex	Complex rudder amplitude (rad/ft or rad/m).
CSTABREG(I,J)	Complex	Complex fin or U-tube tank amplitude (rad/ft or rad/m).

Notes: The above arrays have dimensions (NWVFREQ, NSEADIR).

Regular wave motions and loads are given only for the first seaway regardless of the number of seaways.

Record 21 - Label for Complex Sea Loads in Regular Waves
Written only if NSTLOAD $\geq$ 1 in Record 6
Format (A38)

LOADRAOLABEL	Char*38	"Complex Sea Load RAOs in Regular Waves"

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Record 22 - Complex Sea Loads in Unit Amplitude Regular Waves for Seaway 1

Written only if NSTLOAD *geq* 1 in Record 6
Format (5('(', E12.6, ',', E12.6, ')', 1X))

CHORSHRREG(I,J,K)	Complex	Complex horizontal shear amplitude (lb/ft or N/m).
CVERTSHRREG(I,J,K)	Complex	Complex vertical shear amplitude (lb/ft or N/m).
CTORSIONREG(I,J,K)	Complex	Complex torsional amplitude (lb·ft/ft or N·m/m).
CVERTBNDREG(I,J,K)	Complex	Complex vertical bending moment amplitude (lb·ft/ft or N·m/m).
CHORBNDREG(I,J,K)	Complex	Complex horizontal bending moment amplitude (lb·ft/ft or N·m/m).

Note: The above arrays have dimensions (NWVFREQ, NSEADIR, NSTLOAD).

Within the motions and loads written for each ship speed, the following sequence of RMS responses in irregular seas is repeated for each seaway if SPECTRUM is not equal to REGULAR.

Record 23 - Label for RMS Motions at CG in Irregular Waves
Format (A36)

RMSCGLABEL	Char*36	"RMS Motions at CG in Irregular Waves"

Record 24 - RMS Motions at Ship Centre of Gravity
Format (10(E12.6, 1X))

RMSSURGE(I)	Real	RMS surge (ft or m).
RMSSWAY(I)	Real	RMS sway (ft or m).
RMSHEAVE(I)	Real	RMS heave (ft or m).

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RMSROLL(I)	Real	RMS roll (degrees).
RMSPITCH(I)	Real	RMS pitch (degrees).
RMSYAW(I)	Real	RMS yaw (degrees).
RMSRUD(I)	Real	RMS rudder deflection (degrees).
RMSSTAB(I)	Real	RMS stabilizer deflection (degrees).
RMSSURGEVEL(I)	Real	RMS surge velocity (ft/s or m/s).
RMSSWAYVEL(I)	Real	RMS sway velocity (ft/s or m/s).
RMSHEAVEVEL(I)	Real	RMS heave velocity (ft/s or m/s).
RMSROLLVEL(I)	Real	RMS roll velocity (deg/s).
RMSPITCHVEL(I)	Real	RMS pitch velocity (deg/s).
RMSYAWVEL(I)	Real	RMS yaw velocity (deg/s).
RMSRUDVEL(I)	Real	RMS rudder velocity (deg/s).
RMSSTABVEL(I)	Real	RMS stabilizer velocity (deg/s).
RMSSURGEACC(I)	Real	RMS surge acceleration (g).
RMSSWAYACC(I)	Real	RMS sway acceleration (g).
RMSHEAVEACC(I)	Real	RMS heave acceleration (g).
RMSROLLACC(I)	Real	RMS roll acceleration (deg/s^2).
RMSPITCHACC(I)	Real	RMS pitch acceleration (deg/s^2).
RMSYAWACC(I)	Real	RMS yaw acceleration (deg/s^2).
RMSRUDACC(I)	Real	RMS rudder acceleration (deg/s^2).
RMSSTABACC(I)	Real	RMS stabilizer acceleration (deg/s^2).

Note: The above arrays have dimension (NSEADIR).

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Record 25 - Label for RMS Motions at Seakeeping Positions in Irregular Waves
Written only if NPOS $\geq$ 1 in Record (8)
Format (A54)

RMSPOSLABEL	Char*54	"RMS Motions at Seakeeping Positions in Irregular Waves"

Record 26 - RMS Motions at Seakeeping Positions
Written only if NPOS $\geq$ 1 in Record (8)
Format (10(E12.6, 1X))

RMSVERTDISP(I,J)	Real	RMS vertical displacement (ft or m).
RMSVERTVEL(I,J)	Real	RMS vertical velocity (ft/s or m/s).
RMSVERTACC(I,J)	Real	RMS vertical acceleration (g).
RMSRELDISP(I,J)	Real	RMS relative vertical displacement (ft or m).
RMSRELVEL(I,J)	Real	RMS relative vertical velocity (ft/s or m/s).
RMSLATDISP(I,J)	Real	RMS lateral displacement (ft or m).
RMSLATVEL(I,J)	Real	RMS lateral velocity (ft/s or m/s).
RMSLATACC(I,J)	Real	RMS lateral acceleration (g).
RMSLATFE(I,J)	Real	RMS lateral force estimator (g).
RMSGFEPORT(I,J)	Real	RMS force estimator function for tips or slides to port (g).
RMSGFEPORTVEL(I,J)	Real	RMS time derivative of port estimator (g/s).
RMSGFESTAR(I,J)	Real	RMS force estimator function for tips or slides to starboard (g).
RMSGFESTARVEL(I,J)	Real	RMS time derivative of starboard estimator (g/s).
RMSLONGDISP(I,J)	Real	RMS longitudinal displacement (ft or m).
RMSLONGVEL(I,J)	Real	RMS longitudinal velocity (ft/s or m/s).

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RMSLONGACC(I,J)	Real	RMS longitudinal acceleration (g).
RMSLONGFE(I,J)	Real	RMS longitudinal force estimator (g).
RMSGFEFORE(I,J)	Real	RMS force estimator function for tips or slides forward (g).
RMSGFEFOREVEL(I,J)	Real	RMS time derivative of forward estimator (g/s).
RMSGFEAFT(I,J)	Real	RMS force estimator function for tips or slides aft (g).
RMSGFEAFTVEL(I,J)	Real	RMS time derivative of aft estimator (g/s).

Note: The above arrays have dimensions (NSEADIR, NPOS).

Record 27 - Label for RMS Sea Loads in Irregular Waves
Written only if NSTLOAD $\geq$ 1 in Record (6)
Format (A32)

RMSLOADLABEL	Char*32	"RMS Sea Loads in Irregular Waves"

Record 28 - RMS Sea Loads
Written only if NSTLOAD $\geq$ 1 in Record (6)
Format (10(E12.6, 1X))

RMSHORSHR(I,J)	Real	RMS horizontal shear (lb or N).
RMSHORSHRVEL(I,J)	Real	RMS time derivative of horizontal shear (lb/s or N/s).
RMSVERTSHR(I,J)	Real	RMS vertical shear (lb or N).
RMSVERTSHRVEL(I,J)	Real	RMS time derivative of vertical shear (lb/s or N/s).
RMSTORSION(I,J)	Real	RMS torsion (lb·ft or N·m).
RMSTORSIONVEL(I,J)	Real	RMS time derivative of torsion (lb·ft/s or N·m/s).

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RMSVERTBND(I,J)	Real	RMS vertical bending moment (lb·ft or N·m).
RMSVERTBNDVEL(I,J)	Real	RMS time derivative of vertical bending moment (lb·ft/s or N·m/s).
RMSHORBND(I,J)	Real	RMS horizontal bending moment (lb·ft or N·m).
RMSHORBNDVEL(I,J)	Real	RMS time derivative of horizontal bending moment (lb·ft/s or N·m/s).

Notes: The above arrays have dimensions (NSEADIR, NSTLOAD).

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Annex B
Program Input

B.1 Input Records

Detailed descriptions of SHIPOP2 input records are given below. Each new input record or sub-record corresponds to a new file line. The format of the input file may be adjusted by inserting extra blanks between any numeric data, and by placing data from within any numeric record on separate lines; however, separate records cannot be combined on a single line. Character strings specifying program options must be uppercase, as shown below.

Record (a), Eighty Character Title
TITLE (columns 1 - 80)

TITLE — Alphanumeric title (maximum of 80 characters) which is written on output.

Record (b), Program Used to Generate Ship Response Amplitude Operators
RAOPROGRAM (character*20)

RAOPROGRAM — Name of program used to generate post-processing file of ship RAOs. The program currently supports only one possible option.

- SHIPMO7 — DREA's ship motion program SHIPMO7. The SHIPMO7 post-processing file must be created by setting the SHIPMO7 input variable OUTPRR to OUTASCII. Annex A describes the format of the updated SHIPMO7 ASCII post-processor output.

Record (c), Name of File with Ship Motion RAOs
RAOFILE (character*20)

RAOFILE — Name of ASCII post-processor file with RAOs generated by SHIPMO7.

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Record (d), System of Units for Input and Output
UNITSYS (character*10)

UNITSYS Unit system. The two possible inputs are:

FPS	FPS units.
METRIC	Metric units.

Record (e), Ship Dimensions
SHIPLEN, NSTA, STACG, DISP, SHIPKG, DRAFTMID, TRIM, LISTDEG (1 real, 1 integer, 6 reals)

SHIPLEN	Length between perpendiculars (ft or m).
NSTA	Number of stations between perpendiculars. Station 0 is located at the forward perpendicular.
STACG	Station number of longitudinal centre of gravity (LCG).
DISP	Ship displacement (long tons or tonnes).
SHIPKG	Height of centre of gravity above baseline (ft or m).
DRAFTMID	Draft of baseline at midships (ft or m).
TRIM	Trim of baseline from bow to stern, + for bow up (ft or m).
LISTDEG	Mean list angle (degrees, + starboard down).

Record (f), Modelling of Roll Dependence on Significant Wave Height
ROLLMODEL (character*20)

ROLLMODEL Method used for modelling roll dependence on significant wave height. The two possible inputs are:

LINEAR	Linear roll dependence.
EXPONENTIAL	Exponential roll dependence.

Note: LINEAR roll dependence will reduce computation time; however, EXPONENTIAL roll dependence will give more accurate results.

Record (f1), Conditions for Input Roll Responses for Long-Crested, Irregular Seas

Read only if ROLLMODEL = EXPONENTIAL in Record (f).
NSPROLL, TPROLL, H1ROLL, H2ROLL (1 integer, 3 reals)

NSPROLL — Number of ship speeds for which RMS roll motions in long-crested beam seas are given (maximum 10). NSPROLL must equal the number of ship speeds for the RAOs generated by SHIPMO7.

TPROLL — Peak wave period for which input RMS roll motions are given. TPROLL does not affect computations, but is merely given as output for reference.

H1ROLL — First significant wave height for input RMS roll motions. H1ROLL must equal the significant wave height (within a two percent tolerance) for which the SHIPMO7 RAOs are generated.

H2ROLL — Second significant wave height for input RMS roll motions.

Note: One Record (f2) is required for each of the NSPROLL ship speeds.

Record (f2), Input Roll Responses for Long-Crested, Irregular Beam Seas

Read only if NSPROLL > 0 in Record (f1).
SPROLL(I), RMSROLLH1(I), RMSROLLH2(I) (3 reals)

SPROLL(I) — Ship speed (knots) for which RMS roll motions are given. The ship speeds SPROLL must equal the ship speeds for the RAOs generated by SHIPMO7.

RMSROLLH1(I) — RMS roll (degrees) in long-crested beam seas for wave height H1ROLL.

RMSROLLH2(I) — RMS roll (degrees) in long-crested beam seas for wave height H2ROLL.

Notes:

1. The ratio of the input RMS roll response to significant wave height must be decreasing with significant wave height. The program terminates if this requirement is not satisfied.
2. The absolute values of RMSROLLH1(I) and RMSROLLH2(I) do not influence SHIPOP2 computations. Instead, the ratios RMSROLLH1(I)/H1ROLL and RMSROLLH2(I)/H2ROLL are used to model nonlinear roll dependence.

Record (g), Wave Climate File Directory
WAVEFILEDIR (character*60)

WAVEFILEDIR Computer directory with wave climate files.

Record (h), Wave Data Source
WAVESOURCE (character*20)

WAVESOURCE Wave data source. The eight possible inputs are:

NORATLPUB	North Atlantic annual public domain wave data from Reference 3.
NORPACPUB	North Pacific annual public domain wave data from Reference 3.
CANLANT	Canadian Atlantic and coastal area wave data from Reference 4.
USERWAVE	User input wave scattergram as defined in Annex E.
NORATLUS	North Atlantic annual wave data from Reference 8.
NORATLWINUS	North Atlantic winter wave data from Reference 8.
NORPACUS	North Pacific annual wave data from Reference 9.
NORPACWINUS	North Pacific winter wave data from Reference 9.

Notes:

1. For WAVESOURCE = NORATLUS, NORATLWINUS, NORPACUS, or NORPACWINUS, the wave data files are proprietary to the US Navy and DND cannot distribute them to third parties.
2. If WAVESOURCE = CANLANT, NORATLUS, NORATLWINUS, NORPACUS, or NORPACWINUS, then Record (h) must be followed by Record (h1) and either Record (h2) or (h3).
3. If WAVESOURCE = USERWAVE, then Record (h) must be followed by Record (h4).

Record (h1), Grid Point Option for Wave Data Source

Read only if WAVESOURCE is CANLANT, NORATLUS, NORATLWINUS, NORPACUS, or NORPACWINUS in Record (h)
GRIDOPTION (character*20)

GRIDOPTION Grid point option. The three possible inputs are:

GENERAL	Program uses wave climate data for general area.
GRIDPOINT	Program uses wave climate data for user specified grid point.
LATLONG	Program uses wave climate data for grid point nearest user input location.

Note: If WAVESOURCE is CANLANT in Record (h), then GRIDOPTION must be either GRIDPOINT or LATLONG.

Record (h2), Grid Point Number

Read only if GRIDOPTION = GRIDPOINT in Record (h1).
IGRIDPOINT, JSUBPOINT (2 integers)

IGRIDPOINT Grid point number.

JSUBPOINT Sub point number.

Note: The grid and sub point numbers must correspond to an existing data point for the wave data source specified in Record (h). If WAVESOURCE = CANLANT, then IGRIDPOINT must be in the range 1-17 and JSUBPOINT should be set to 1. Grid areas for the CANLANT operational area are shown in Figure D.1 and are tabulated in Table D.1 of Annex D.1. Grid points for the North Atlantic and North Pacific shown in Figures D.2 and D.3 and are tabulated in Tables D.3 and D.4 of Annexes D.2 and D.3.

Record (h3), Latitude and Longitude of Operational Area

Read only if GRIDOPTION = LATLONG in Record (h1).
USERLAT, USERLONG (2 reals)

USERLAT Latitude in northern Hemisphere (0 degrees $\leq$ USERLAT $\leq$ 90 degrees).

USERLONG Longitude (degrees, + for east of prime meridian).

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Record (h4), File name for wave scattergram
Read only if WAVESOURCE = USERWAVE in Record (h).
USERWAVEFILE (char*50)

USERWAVEFILE Wave scattergram file with format given in Annex E.

Record (i), Wave Spectrum
SPECTRUM (character*20)

SPECTRUM Wave spectrum. The two possible inputs are:

BRETSCHNEIDER	Bretschneider spectrum.
JONSWAP	JONSWAP spectrum.

Note: The Bretschneider spectrum is recommended for open ocean sites.

Record (j), Wave Spreading Angle
SPREADANGLE (real)

SPREADANGLE Wave spreading angle (degrees). SPREADANGLE = 0.0 for long-crested seas.

Record (k), Speed Weight Option
SPEEDOPTION (character*10)

SPEEDOPTION Option for speed weights for operability computations. The two possible inputs are:

DEFAULT	Program assigns default weights to ship speeds.
USERINPUT	User input speed weights.

Record (k1), Number of Ship Speeds
Read only if SPEEDOPTION = USERINPUT in Record (k).
NSPEEDUSER (integer)

NSPEEDUSER Number of speeds for which speed weights are given. NSPEEDUSER must equal the number of speeds given in the SHIPMO7 RAO file (maximum value 10).

Note: One Record (k2) is required for each of the NSPEEDUSER ship speeds.

Record (k2), Ship Speeds and Weights
Read only if SPEEDOPTION = USERINPUT in Record (k).
SPEEDUSER(I), SPEEDWEIGHT(I) (2 reals)

SPEEDUSER(I) Ship speed for which speed weight is given. SPEEDUSER must correspond to speeds given in the SHIPMO7 post-processor file with RAOs.

SPEEDWEIGHT(I) Ship speed weight. Input SPEEDWEIGHT values are normalized by SHIPOP2 such that their sum is equal to one.

Record (l), Heading Weight Option
HEADOPTION (character*10)

HEADOPTION Option for heading weight for operability computations. The two possible inputs are:

DEFAULT	Program assigns default weights to headings.
USERINPUT	User input heading weights.

Record (l1), Number of Headings
Read only if HEADOPTION = USERINPUT in Record (l).
NHEADUSER (integer)

NHEADUSER Number of headings for which heading weights are given. NHEADUSER must equal the number of headings given in the SHIPMO7 RAO file (maximum value 36).

Note: One Record (k2) is required for each of the NHEADUSER ship headings.

Record (l2), Ship Headings and Weights
Read only if HEADOPTION = USERINPUT in Record (l).
HEADUSER(I), HEADWEIGHT(I) (2 reals)

HEADUSER(I) Ship heading for which heading weight is given. HEADUSER must correspond to headings given in the SHIPMO7 RAO file.

HEADWEIGHT(I) Ship heading weight. Input HEADWEIGHT values are normalized by SHIPOP2 such that their sum is equal to one.

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Record (m), Wind Option

WINDOPTION (character*20)

WINDOPTION Option for wind computations. The four possible inputs are:

NOWIND	No wind effects.
AIROP	Program considers effect of acceptable relative wind envelope on operability.
MII	Motion-induced interruption computations include wind forces.
MIIANDAIROP	Wind effects on both motion-induced interruptions and aircraft operations are included.

Record (n), Wind Speed Coefficients

Read only if WINDOPTION is equal to AIROP, MII, or MIIANDAIROP in Record (m).

WINDCOA, WINDCOB, WINDCOC (3 reals)

Wind speed is assumed to be a function of wave height as follows:

$$\overline{U}_{19.5m} = A\,H_s^2 + B\,H_s + C \qquad \text{(B.1)}$$

where $\overline{U}_{19.5m}$ is wind speed (knots) and H_s is significant wave height (ft or m).

WINDCOA Wind coefficient A (knots/ft^2 or knots/m^2). If input as 0.0, a default value of 0.0 is used.

WINDCOB Wind coefficient B (knots/ft or knots/m). If input as 0.0, a default value of 1.079 knots/ft or 3.539 knots/m is used.

WINDCOC Wind coefficient C (knots). If input as 0.0, a default value of 6.69 knots is used.

Record (o), Number of Relative Wind Directions for Wind Operability Envelope

Read only if WINDOPTION = AIROP or MIIANDAIROP in Record (m).

NWINDDIR (integer)

NWINDDIR Number of wind directions for acceptable relative wind envelope (minimum 2, maximum 36).

Note: One Record (o1) is required for each of the NWINDDIR relative wind directions.

Record (o1), Relative Wind Directions and Acceptable Relative Wind Speeds
Read only if NWINDDIR > 0 in Record (o).
WINDDIR(I), WINDLIMIT(I) (2 reals)

WINDDIR(I) Relative wind direction (from, degrees). The direction convention for input relative wind direction is the same as for the true wind direction γ_a shown in Figure 2. WINDDIR values must be in ascending order, ranging from 0 to at least 180 degrees. If the maximum WINDDIR value equals 180 degrees, then the acceptable relative wind envelope is assumed to be symmetrical.

WINDLIMIT(I) Limiting relative wind speed (knots).

Note: The effects of superstructure sheltering, if any, should be included by increasing the allowable relative wind speed for headings near 0 degrees.

Record (p), Number of Motion Criteria
NCRITERIA (integer)

NCRITERIA Number of ship motion criteria (maximum 20).

Note: One Record (q) and one record (qX) is required for each ship motion criterion, where X is an integer between 1 and 21.

Record (q), Criterion Label
Read only if NCRITERIA > 0 in Record (o).
CRITERIA(I) (character*15)

CRITERIA(I) Label for criterion I. The label must begin with one of the following character strings specifying the criterion type, but can have additional characters used to distinguish between criteria locations. For example, if there were slamming criteria for two locations then the two criteria could be labelled SLAMMING 1 and SLAMMING 2. The 21 possible inputs are:

ROLL	Roll.
PITCH	Pitch.
WETNESS	Deck wetness.
EMERGE	Emergence.

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SLAMMING	Slamming.
VERTDIS	Vertical displacement.
VERTVEL	Vertical velocity.
VERTACC	Vertical acceleration.
RELDIS	Relative displacement.
LATACC	Lateral acceleration.
LONGACC	Longitudinal acceleration.
LATFE	Lateral force estimator.
LONGFE	Longitudinal force estimator.
SLIMII	Sliding motion-induced interruptions.
TIPMII	Tipping motion-induced interruptions.
VELROLL	Roll velocity.
LONGFIX	Fixture longitudinal relative displacement.
LATFIX	Fixture lateral relative displacement.
VERTFIX	Fixture vertical relative displacement.
MSIMAX	Maximum motion sickness incidence.
MSITDAY	Motion sickness incidence after specified number of days.

Record (q1), Roll Criterion

Read only if CRITERIA(I) begins with ROLL in Record (q).
ROLLLIM (real)

ROLLLIM	Limiting RMS roll (degrees). If input as 0.0, a default value of 4.0 degrees is used.

Record (q2), Pitch Criterion

Read only if CRITERIA(I) begins with PITCH in Record (q).
PITCHLIM (real)

PITCHLIM	Limiting RMS pitch (degrees). If input as 0.0, a default value of 1.5 degrees is used.

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Record (q3), Deck Wetness Criterion

Read only if CRITERIA(I) begins with WETNESS in Record (q).
WETLIM, XSTWET, YWET, ZWETBL (4 reals)

WETLIM Limiting number of deck wetnesses per hour. If input as 0.0, a default value of 30 wetnesses per hour is used.

XSTWET Station number.

YWET Y coordinate (ft or m).

ZWETBL Height above baseline (ft or m).

Record (q4), Emergence Criterion

Read only if CRITERIA(I) begins with EMERGE in Record (q).
EMERGELIM, XSTEMERGE, YEMERGE, ZEMERGEBL (4 reals)

EMERGELIM Limiting number of emergences per hour. If input as 0.0, a default value of 30 wetnesses per hour is used.

XSTEMERGE Station number.

YEMERGE Y coordinate (ft or m).

ZEMERGEBL Height above baseline (ft or m).

Record (q5), Slamming Criterion

Read only if CRITERIA(I) begins with SLAMMING in Record (q).
SLAMLIM, XSTSLAM, YSLAM, ZSLAMBL, VTHRESH (5 reals)

SLAMLIM Limiting number of slams per hour. If input as 0.0, a default value of 20 slams per hour is used.

XSTSLAM Station number.

YSLAM Y coordinate (ft or m).

ZSLAMBL Height above baseline (ft or m).

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VTHRESH Slamming threshold velocity (ft/s or m/s). Reference 13 proposes the following equation for threshold velocity:

$$\hat{v} = 0.377 \sqrt{\frac{g\,L}{k_s}} \tag{B.2}$$

where k_s is the slamming form factor, which can be obtained from SHIPMO7 output. Note that k_s, and thus $\hat{v}$, is highly sensitive to section geometry.

Record (q6), Vertical Displacement Criterion

Read only if CRITERIA(I) begins with VERTDIS in Record (q).
VDISLIM, XSTVDIS, YVDIS, ZVDISBL (4 reals)

VDISLIM Limiting RMS vertical displacement (ft of m). If input as 0.0, a default value of 3.28 ft or 1.0 m is used.

XSTVDIS Station number.

YVDIS Y coordinate (ft or m).

ZVDISBL Height above baseline (ft or m).

Record (q7), Vertical Velocity Criterion

Read only if CRITERIA(I) begins with VERTVEL in Record (q).
VVELLIM, XSTVVEL, YVVEL, ZVVELBL (4 reals)

VVELLIM Limiting RMS vertical velocity (ft/s or m/s). If input as 0.0, a default value of 3.28 ft/s or 1.0 m/s is used.

XSTVVEL Station number.

YVVEL Y coordinate (ft or m).

ZVVELBL Height above baseline (ft or m).

Record (q8), Vertical Acceleration Criterion

Read only if CRITERIA(I) begins with VERTACC in Record (q).
VACCLIM, XSTVACC, YVACC, ZVACCBL (4 reals)

VACCLIM Limiting RMS vertical acceleration (g). If input as 0.0, a default value of 0.20 g is used.

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XSTVACC Station number.

YVACC Y coordinate (ft or m).

ZVACCBL Height above baseline (ft or m).

Record (q9), Relative Displacement Criterion

Read only if CRITERIA(I) begins with RELDIS in Record (q).
RELDLIM, XSTRELD, YRELD, ZRELDBL (4 reals)

RELDLIM Limiting RMS relative displacement (ft or m). If input as 0.0, a default value of 999 ft or 999 m is used because relative displacement is rarely used as a motion criterion and has no standard value.

XSTRELD Station number.

YRELD Y coordinate (ft or m).

ZRELDBL Height above baseline (ft or m).

Record (q10), Lateral Acceleration Criterion

Read only if CRITERIA(I) begins with LATACC in Record (q).
LATALIM, XSTLATA, YLATA, ZLATABL (4 reals)

LATALIM Limiting RMS lateral acceleration (g). If input as 0.0, a default value of 0.07 g is used.

XSTLATA Station number.

YLATA Y coordinate (ft or m).

ZLATABL Height above baseline (ft or m).

Record (q11), Longitudinal Acceleration Criterion

Read only if CRITERIA(I) begins with LONGACC in Record (q)
LONGALIM, XSTLONGA, YLONGA, ZLONGABL (4 reals)

LONGALIM Limiting RMS longitudinal acceleration (g). If input as 0.0, a default value of 0.07 g is used.

XSTLONGA Station number.

YLONGA Y coordinate (ft or m).

ZLONGABL Height above baseline (ft or m).

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Record (q12), Lateral Force Estimator Criterion
Read only if CRITERIA(I) begins with LATFE in Record (q)
LATFELIM, XSTLATFE, YLATFE, ZLATFEBL (4 reals)

LATFELIM Limiting RMS lateral force estimator (g). If input as 0.0, a default value of 0.07 g is used.

XSTLATFE Station number.

YLATFE Y coordinate (ft or m).

ZLATFEBL Height above baseline (ft or m).

Record (q13), Longitudinal Force Estimator Criterion
Read only if CRITERIA(I) begins with LONGFE in Record (q)
LONGFELIM, XSTLONGFE, YLONGFE, ZLONGFEBL (4 reals)

LONGFELIM Limiting RMS longitudinal force estimator (g). If input as 0.0, a default value of 0.07 g is used.

XSTLONGFE Station number.

YLONGFE Y coordinate (ft or m).

ZLONGFEBL Height above baseline (ft or m).

Record (q14), Sliding Motion-Induced Interruption Criterion
Read only if CRITERIA(I) begins with SLIMII in Record (q)
SLILIM, XSTSLI, YSLI, ZSLIBL, FRILAT, FRILONG, CDALAT, CDALONG, BODYMASS (9 reals)

SLILIM Limiting number of sliding events per minute. If input as 0.0, a default value of 1.5 MIIs per minute is used.

XSTSLI Station number.

YSLI Y coordinate (ft or m).

ZSLIBL Height above baseline (ft or m).

FRILAT Lateral friction coefficient. If a value of 0.0 is input, then a default value of 0.70 is used.

FRILONG Longitudinal friction coefficient. If a value of 0.0 is input, then a default value of 0.70 is used.

CDALAT Lateral drag coefficient × drag area (ft^2 or m^2).

CDALONG Longitudinal drag coefficient × drag area. (ft^2 or m^2).

BODYMASS Mass of sliding person or object (slugs or kg). If a value of 0.0 is input, then a default of 4.8 slugs or 70 kg is used.

Notes:

1. Input terms CDALAT, CDALONG, and BODYMASS are used for wind force computations and only influence results when WINDOPTION = MII or MIIANDAIROP in Record (I).
2. The default body mass represents a typical man facing forward or aft.
3. The effects of superstructure sheltering on wind effects are not included in the sliding calculations.

Record (q15), Tipping Motion-Induced Interruption Criterion

Read only if CRITERIA(I) begins with TIPMII in Record (q)
TIPLIM, XSTTIP, YTIP, ZTIPBL, TIPLAT, TIPLONG, CDALAT, CDALONG, BODYMASS, BODYHEIGHT, INERTCO, DAMPCO, STIFFCO, STEADYWI (14 reals)

TIPLIM Limiting number of tipping events per minute. If input as 0.0, default value of 1.5 MIIs per minute is used.

XSTTIP Station number.

YTIP Y coordinate (ft or m).

ZTIPBL Height above baseline (ft or m).

TIPLAT Lateral tipping coefficient. If a value of 0.0 is input, then a default value of 0.25 is used.

TIPLONG Longitudinal tipping coefficient. If a value of 0.0 is input, then a default value of 0.17 is used.

CDALAT Lateral drag coefficient × drag area (ft^2 or m^2).

CDALONG Longitudinal drag coefficient × drag area. (ft^2 or m^2).

BODYMASS Mass of tipping person or object (slugs or kg). If a value of 0.0 is input, then a default of 4.8 slugs or 70 kg is used.

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BODYHEIGHT Height of CG of person or object above deck (ft or m). If a value of 0.0 is input, then a default of 2.95 ft or 0.9 m is used.

INERTCO Tipping inertia coefficient, $I/(m\ h^2)$. If a value of 0.0 is input, then a default of 1.07 is used.

DAMPCO Tipping damping coefficient (fraction of critical). If a value of 0.0 is input, then a default of 0.7 is used.

STIFFCO Tipping stiffness coefficient, $K/(m\ g\ h)$. If a value of 0.0 is input, then a default of 2.0 is used. For an object unable to compensate for tipping, a value of $\sqrt{2}$ is recommended.

STEADYWI Steady wind flag indicating if steady wind influences incidence of tipping.

STEADYWI = 0 Steady wind does not influence tipping. This case occurs when a person is able to compensate for steady wind by leaning.

STEADYWI = 1 Steady wind influences tipping. This case occurs when there is no compensation for steady wind, and is suitable for an object on the deck.

Notes:

1. Input terms CDALAT, CDALONG, BODYMASS, BODYHEIGHT, INERTCO, DAMPCO, STIFFCO, and STEADYWI are used for wind force computations and only influence results when WINDOPTION = MII or MIIANDAIROP in Record (l).
2. The default values for the above variables represent a typical man facing fore-aft. If CDALAT and CDALONG are input as zero, then SHIPOP2 does not modify them because drag coefficients of zero can be used to represent a body totally sheltered from wind (e.g. inside the ship).
3. The effects of superstructure sheltering on wind effects are not included in the tipping calculations.

Record (q16), Roll Velocity Criterion

Read only if CRITERIA(I) begins with VELROLL in Record (q).
VELROLLLLIM (real)

VELROLLLIM Limiting RMS roll velocity (degrees/second). If input as 0.0, a default value of 999 deg/s is used.

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Record (q17), Longitudinal Fixture Relative Displacement

Read only if CRITERIA(I) begins with LONGFIX in Record (q).
LONGFIXLIM, XSTFIX, YFIX, ZFIXBL, XSTLAUNCH, YLAUNCH, ZLAUNCHBL, TTRANSIT (8 reals)

LONGFIXLIM Limiting RMS longitudinal motion of fixture relative to projectile trajectory (ft or m). If input as 0.0, a default value of 999 ft or m is used.

XSTFIX Station number of fixture.

YFIX Y coordinate of fixture (ft or m).

ZFIXBL Height above baseline of fixture (ft or m).

XSTLAUNCH Station number of launch point.

YLAUNCH Y coordinate of launch point (ft or m).

ZLAUNCHBL Height above baseline of launch point (ft or m).

TTRANSIT Time for projectile to travel from launcher to vicinity of fixture (s).

Record (q18), Lateral Fixture Relative Displacement

Read only if CRITERIA(I) begins with LATFIX in Record (q).
LATFIXLIM, XSTFIX, YFIX, ZFIX, XLAUNCH, YLAUNCH, ZLAUNCHBL, TTRANSIT (8 reals)

LATFIXLIM Limiting RMS lateral motion of fixture relative to projectile trajectory (ft or m). If input as 0.0, a default value of 999 ft or m is used.

XSTFIX Station number of fixture.

YFIX Y coordinate of fixture (ft or m).

ZFIX Height above baseline of fixture (ft or m).

XSTLAUNCH Station number of launch point.

YLAUNCH Y coordinate of launch point (ft or m).

ZLAUNCHBL Height above baseline of launch point (ft or m).

TTRANSIT Time for projectile to travel from launcher to vicinity of fixture (s).

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Record (q19), Vertical Fixture Relative Displacement
Read only if CRITERIA(I) begins with VERTFIX in Record (q).
VERTFIXLIM, XSTFIX, YFIX, ZFIXBL, XSTLAUNCH, YLAUNCH, ZLAUNCHBL, TTRANSIT (8 reals)

VERTFIXLIM Limiting RMS vertical motion of fixture relative to projectile trajectory (ft or m). If input as 0.0, a default value of 999 ft or m is used.

XSTFIX Station number of fixture.

YFIX Y coordinate of fixture (ft or m).

ZFIXBL Height above baseline of fixture (ft or m).

XSTLAUNCH Station number of launch point.

YLAUNCH Y coordinate of launch point (ft or m).

ZLAUNCHBL Height above baseline of launch point (ft or m).

TTRANSIT Time for projectile to travel from launcher to vicinity of fixture (s).

Record (q20), Maximum Motion Sickness Incidence Criterion
Read only if CRITERIA(I) begins with MSIMAX in Record (q).
MSIMAXLIM, XSTMSIMAX, YMSIMAX, ZMSIMAXBL (4 reals)

MSIMAXLIM Limiting maximum motion sickness incidence (percent). If input as zero, then a default value of 20 percent is used.

XSTMSIMAX Station number.

YMSIMAX Y coordinate (ft or m).

ZMSIMAXBL Height above baseline (ft or m).

Record (q21), Motion Sickness Incidence After Exposure Criterion
Read only if CRITERIA(I) begins with MSITDAY in Record (q).
MSITDAYLIM, XSTMSITDAY, YMSITDAY, ZMSITDAYBL, TDAY (5 reals)

MSITDAYLIM Limiting motion sickness incidence (percent) after time TDAY exposure to motions. If input as zero, then a default value of 20 percent is used.

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XSTMSITDAY	Station number.
YMSITDAY	Y coordinate (ft or m).
ZMSITDAYBL	Height above baseline (ft or m).
TDAY	Time (days) after initial exposure to motions. If input as zero, then a default value of 2 days is used.

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B.2 Sample Input

```
Shipop2 sample case, frigate in North Atlantic
SHIPMO7                    <----- Program generating RAOs
shipop2mo.dat               <----- Shipmo postprocessing file
METRIC                 <----- SHIPOP units
124.5 20 10.37 4731.8 6.23 5.025 0.152  0.0  <--- Ship properties
EXPONENTIAL            <----- Roll model
1  9.7  3.25  6.5
18.0   3.22   6.01
D:\Shipop2\Wave
NORATLPUB          <----- Wave source
BRETSCHNEIDER             <----- Spectrum
0.0                          <----- Spreading angle
DEFAULT                   <----- Speed weights
DEFAULT                   <----- Heading weights
MIIANDAIROP           <----- Wind option
0.0  0.0  0.0              <----- Wind speed coefficients
7              <----- Number of directions for air envelope
0  50.0
30.0  50.0
60.0  35.0
90.0  35.0
120.0 35.0
150.0 20.0
180.0 20.0
16              <----- Number of criteria
ROLL
4.0
PITCH
1.5
WETNESS
30  3.0 0.0  12.140
SLAMMING
20  3.0 0.0 0.0  0.0
VERTDIS
1.0   3.0   0.0  13.0
VERTVEL
1.0   3.0  0.0  13.0
VERTACC
0.20  3.0  0.0  13.0
RELDIS
```

```
2.0  3.0  0.0 13.0
LATACC
0.07  3.0 0.0 13.0
LONGACC
0.07  3.0 0.0 13.0
LATFE
0.07  3.0 0.0 13.0
LONGFE
0.07  3.0  0.0 13.0
SLIMII 1
1.5  3.0  0.0  13.0   0.70  0.70
0.34  0.78   70.0
TIPMII
1.5 3.0  0.0  13.0   0.25  0.17
0.34  0.78  70.0 0.9   1.07  0.7 2.0   0
MSIMAX
15.0  3.0  0.0  13.0
MSITDAY
10.0 3.0  0.0  13.0  2.0
```

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Annex C
Sample Output

```
SHIPOP --- SHIP OPERABILITY IN WAVES     PROGRAM VERSION 2.0, AUGUST 2000

SHIPOP2 sample case, frigate in North Atlantic
15:05:18 23-Aug-2000

Program from which RAOs are read :  SHIPMO7

Name of SHIPMO7 post-processing file :  shipop2mo.dat

System of units for operability computations : METRIC


******  PRINCIPAL SHIP DIMENSIONS AND ROLL DAMPING  *****

   Length between perpendiculars =  124.500 m
                    Displacement =  4731.80 tonnes
            Number of stations :    20
          Station number for CG :    10.37
     Height of CG above baseline :    6.230 m
   Draft of baseline at midships .    5.025 m
                   Trim by stern .    0.152 m
Mean list angle (+ to starboard) :     0.00 degrees

Model for variation of roll motions with wave height . EXPONENTIAL

User input RMS roll in beam seas for modelling nonlinearity of roll RAOs

  Reference wave period       9.70 seconds

     Speed    |     Hs    RMS roll    |     Hs    RMS roll
    (knots)   |    (m )    (deg)      |    (m )    (deg)
     18.0     |    3.25     3.22      |    6.50     6.01
```

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```
*****   SUMMARY OF WIND OPTIONS   *****

   User input : MIIANDAIROP

Operability computations include wind effects

Wind velocity is a function of significant wave height as follows:

   Vwind = A*Hs**2 + B*Hs + C

   Vwind = wind velocity (knots)
       A =  0.000 knots/m **2
       B =  3.539 knots/m
       C =  6.690 knots


Wind effects included in MII computations.

Operability computations include air operations.

Relative wind direction = 0 degrees for head wind.

***  Input relative wind operability envelope ***

Relative wind direction       Limiting relative velocity
      (degrees)                       (knots)
         0.0                            50.0
        30.0                            50.0
        60.0                            35.0
        90.0                            35.0
       120.0                            35.0
       150.0                            20.0
       180.0                            20.0
```

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***** SUMMARY OF MOTION CRITERIA *****

Number of operability criteria : 16

Label	Criteria	Station	Y (m)	Z (m)
ROLL	4.00 degrees RMS roll angle			
PITCH	1.50 degrees RMS pitch angle			
WETNESS	30.0 wetnesses per hour	3.00	0.00	7.17 wrt waterline 12.14 wrt baseline
SLAMMING	20.0 slams per hour (0.00 m /s threshold velocity)	3.00	0.00	-4.97 wrt waterline 0.00 wrt baseline
VERTDIS	1.00 m vertical displacement	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
VERTVEL	1.00 m /s vertical velocity	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
VERTACC	0.200 g vertical acceleration	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
RELDIS	2.00 m relative displacement	3.00	0.00	8.03 wrt waterline 13.00 wrt baseline
LATACC	0.070 g lateral acceleration	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
LONGACC	0.070 g longitudinal acceleration	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
LATFE	0.070 g lateral force estimator	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
LONGFE	0.070 g longitudinal force estimator	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
SLIMII 1	1.50 Sliding MII's per minute Friction coef. : lateral = 0.700, longitudinal = 0.700 Drag coef * Area (m **2) lateral = 0.340, longitudinal = 0.780 Mass = 70.000 kg	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
TIPMII	1.50 Tipping MII's per minute Tipping coef : lateral = 0.250, longitudinal = 0.170 Drag coef * Area (m **2) lateral = 0.340, longitudinal = 0.780 Mass, m = 70.000 kg Body CG at h = 0.900 m above deck Inertial coef I/Mh**2 = 1.070 Damping coef = 0.700 Stiffness coef K/(mgh) = 2.000 Steady wind flag = 0.0 Computed natural tipping frequency = 4.062 rad/s	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
MSIMAX	15.0 % max motion sickness incidence	3.00	0.00	6.83 wrt CG 13.00 wrt baseline
MSITDAY	10.0 % motion sickness incidence after 2.00 days	3.00	0.00	6.83 wrt CG 13.00 wrt baseline

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```
***** DATA FROM SHIPMO7 POST PROCESSING FILE *****

Program name : SHIPMO7.2

Run title :
Shipmo7 input for Shipop2 example, Frigate
05-Nov-1998 11:57:40
Output system of units    : METRIC
Water type                : SALT
Hydrodynamic coefficients : BOUND2D
Wave spectrum             : BRETSCHNEIDER

Ship particulars
Length between perpendiculars :      124.500 m
Number of stations            :   21
Displacement                  :     4731.780 tonnes
Distance from FP to LCB       :       64.553 m
Midships draft                :        5.025 m
Trim by stern                 :       -0.135 m
VCG above keel, KG            :        6.230 m
Beam at midships              :       14.803 m

Water density   :     1025.000 kg/m3
Gravity                9.807 m/s2


Number of stations for sea loads :    0

Number of seakeeping positions      0

Number of ship speeds :    1
Ship speeds (knots) :
  18.00

Number of sea directions :    7
Sea directions (degrees) :
    0.0   30.0   60.0   90.0  120.0  150.0  180.0

Number of seaways :    2
   Hsig (m)      T (s)
  3.250        9.700
  6.500        9.700

Wave frequencies
  Number    .   18
  Minimum   :     0.200 rad/s
  Increment :     0.100 rad/s
```

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***** SPEED WEIGHTS FOR OPERABILITY *****

Speed weight option : DEFAULT

Speed (kts)	Weight (Normalized)
18.0	1.000

***** HEADING WEIGHTS FOR OPERABILITY *****

Heading weight option : DEFAULT

Heading (deg)	Weight (Normalized)
0.0	0.083
30.0	0.167
60.0	0.167
90.0	0.167
120.0	0.167
150.0	0.167
180.0	0.083

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******** WAVE AND WIND CLIMATE SUMMARY ********

File directory : c:\Kevin\Shipop2\Wave
Wave data source : NORATLPUB
Wave spectrum : BRETSCHNEIDER
Wave type : LONG CRESTED
Grid option : GENERAL
Operational area : North Atlantic
Season : Annual

Cumulative Distribution of Significant Wave Heights with Corresponding Wind Speeds
based on Quadratic Function

Wave height interval for climatic data is 0.5 m

Sig Wave Height (m)	Wind Speed (knots)	Cumulative Distribution (per cent)
0.000	6.690	0.000
1.000	10.229	22.546
2.000	13.768	48.441
3.000	17.307	67.135
4.000	20.846	79.645
5.000	24.385	87.611
6.000	27.924	92.790
7.000	31.463	95.980
8.000	35.002	97.775
9.000	38.541	98.835
10.000	42.080	99.385
11.000	45.619	99.671
12.000	49.158	99.813
13.000	52.697	99.881
14.000	56.236	99.949
15.000	59.775	99.970
16.000	63.314	99.992
17.000	66.853	99.995
18.000	70.392	99.999
19.000	73.931	100.000
20.000	77.470	100.000
21.000	81.009	100.000
22.000	84.548	100.000
23.000	88.087	100.000
24.000	91.626	100.000

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********** OPERABILITY COMPUTATIONS FOR SHIP SPEED OF 18.0 KNOTS **********

Operational area : North Atlantic
Season : Annual
Wave spectrum : BRETSCHNEIDER
Wave type : LONG CRESTED

ROLL CORRECTION FACTORS FOR SHIP SPEED OF 18.00 knots
GAMMA = 1.0 for reference wave height Href of 3.25 m
Exponential roll nonlinearity model

ALPHAROLL = Roll nonlinearity exponent

GAMMA = Roll correction factor
Hs = Significant wave height

GAMMA(Hs) = (Hs/Href)**(-ALPHAROLL)

ALPHAROLL = 0.09970

Sig Wave Ht (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
GAMMA	1.12	1.05	1.01	0.98	0.96	0.94	0.93	0.91	0.90	0.89	0.89	0.88

COMPUTED RMS MOTIONS AT CG IN LONG CRESTED SEAS FOR REFERENCE WAVE CONDITIONS

Spectrum = BRETSCHNEIDER Sig wave height = 3.25 m Peak wave period = 9.70 seconds

Heading (deg)	Surge (m)	Sway (m)	Sway Acc (g)	Heave (m)	Heave Acc (g)	Roll (deg)	Pitch (deg)	Yaw (deg)
0.0	2.012	0.000	0.000	0.229	0.002	0.000	0.639	0.000
30.0	1.460	0.587	0.004	0.278	0.003	1.697	0.632	1.657
60.0	0.615	0.564	0.012	0.474	0.010	3.751	0.728	1.298
90.0	0.000	0.630	0.040	0.823	0.065	3.224	0.055	0.118
120.0	0.160	0.287	0.022	0.688	0.070	2.270	0.990	0.353
150.0	0.146	0.092	0.007	0.490	0.052	1.097	0.987	0.160
180.0	0.133	0.000	0.000	0.426	0.046	0.000	0.931	0.000

COMPUTED RMS MOTIONS AT CG IN LONG CRESTED SEAS FOR SECOND WAVE CONDITION USED FOR ROLL NONLINEARITY

Spectrum = BRETSCHNEIDER Sig wave height = 6.50 m Peak wave period = 9.70 seconds

Heading (deg)	Surge (m)	Sway (m)	Sway Acc (g)	Heave (m)	Heave Acc (g)	Roll (deg)	Pitch (deg)	Yaw (deg)
0.0	4.024	0.000	0.000	0.458	0.003	0.000	1.279	0.000
30.0	2.921	1.374	0.008	0.555	0.005	3.167	1.265	3.314
60.0	1.229	1.129	0.024	0.948	0.019	7.002	1.456	2.596
90.0	0.000	1.261	0.079	1.646	0.130	6.017	0.109	0.236
120.0	0.321	0.573	0.044	1.377	0.140	4.238	1.981	0.706
150.0	0.291	0.184	0.015	0.980	0.104	2.048	1.973	0.321
180.0	0.266	0.000	0.000	0.853	0.092	0.000	1.861	0.000

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***** LIMITING CONDITIONS AND CRITERIA *****

Speed : 18.0 knots
Modelling of roll response : EXPONENTIAL
Spectrum : BRETSCHNEIDER
Wave type : LONG CRESTED

****** Allowable Wind Speeds and Associated Wave Heights for Air Operations ******

Heading = 180 degrees for head seas

Heading (degrees)	Wind speed range (knots)	Wave height range based on quadratic wind-wave equation (m)
0	0.00 - 68.00	0.00 - 17.32
30	0.00 - 64.77	0.00 - 16.41
60	0.00 - 56.51	0.00 - 14.08
90	0.00 - 46.65	0.00 - 11.29
120	0.00 - 38.51	0.00 - 8.99
150	0.00 - 33.59	0.00 - 7.60
180	0.00 - 32.00	0.00 - 7.15

******* Limiting Significant Wave Heights (m) *******

Heading = 180 degrees for head seas

Heading	Peak wave period (s)														
(deg)	3.2	4.8	6.3	7.5	8.6	9.7	10.9	12.4	13.8	15.0	16.4	18.0	20.0	22.5	25.7
0	8.5	8.6	7.3	7.1	6.6	5.3	4.6	4.1	3.9	3.8	3.8	3.7	3.8	3.9	3.8
30	14.9	9.2	8.4	8.1	6.3	5.1	4.5	4.1	3.9	3.8	3.8	3.8	3.8	3.9	3.8
60	14.9	4.0	3.0	3.0	3.2	3.5	3.8	3.7	3.7	3.8	3.8	3.8	3.9	4.0	3.9
90	4.0	1.6	1.5	1.6	1.9	2.2	2.4	2.7	3.2	3.7	4.0	3.9	4.0	4.1	4.0
120	12.4	3.3	1.2	1.0	1.0	1.0	1.2	1.4	1.6	1.8	2.1	2.5	3.0	3.7	3.7
150	8.9	7.3	2.6	1.4	1.2	1.1	1.2	1.3	1.5	1.6	1.8	2.1	2.5	3.1	3.5
180	7.9	7.3	3.6	1.8	1.3	1.2	1.2	1.3	1.4	1.6	1.8	2.1	2.5	3.0	3.4

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******* Limiting Criteria *******

Heading (degrees)	Peak wave period (s) 3.2	4.8	6.3	7.5	8.6
0	MSIMAX	RELDIS	RELDIS	RELDIS	VERTDIS
30	RELDIS	RELDIS	RELDIS	RELDIS	VERTDIS
60	RELDIS	LATFE	LATFE	ROLL	ROLL
90	LATFE	MSIMAX	MSIMAX	MSIMAX	MSIMAX
120	SLAMMING	MSIMAX	MSIMAX	MSIMAX	MSIMAX
150	SLIMII 1	SLAMMING	MSIMAX	MSIMAX	MSIMAX
180	SLIMII 1	SLAMMING	MSIMAX	MSIMAX	MSIMAX

Heading (degrees)	Peak wave period (s) 9.7	10.9	12.4	13.8	15.0
0	VERTDIS	VERTDIS	VERTDIS	VERTDIS	VERTDIS
30	VERTDIS	VERTDIS	VERTDIS	VERTDIS	VERTDIS
60	ROLL	VERTDIS	VERTDIS	VERTDIS	VERTDIS
90	LATFE	LATFE	LATFE	LATFE	LATFE
120	MSIMAX	MSIMAX	MSIMAX	MSIMAX	MSIMAX
150	MSIMAX	MSIMAX	MSIMAX	MSIMAX	MSIMAX
180	MSIMAX	MSIMAX	MSIMAX	MSIMAX	MSIMAX

Heading (degrees)	Peak wave period (s) 16.4	18.0	20.0	22.5	25.7
0	VERTDIS	VERTDIS	VERTDIS	VERTDIS	VERTDIS
30	VERTDIS	VERTDIS	VERTDIS	VERTDIS	VERTDIS
60	VERTDIS	VERTDIS	VERTDIS	VERTDIS	VERTDIS
90	VERTDIS	VERTDIS	VERTDIS	VERTDIS	VERTDIS
120	MSIMAX	MSIMAX	MSIMAX	VERTDIS	VERTDIS
150	MSIMAX	MSIMAX	MSIMAX	MSIMAX	VERTDIS
180	MSIMAX	MSIMAX	MSIMAX	MSIMAX	VERTDIS

****** Minimum Limiting Wave Heights for Joint Wave Period Distributions ******

Heading = 180 degrees for head seas

Heading (degrees)	Central 50% Wave Periods Hs (m)	Criteria	Central 95% Wave Periods Hs (m)	Criteria	All Wave Periods Hs (m)	Criteria
0	3.93	VERTDIS	3.74	VERTDIS	3.74	VERTDIS
30	3.90	VERTDIS	3.76	VERTDIS	3.76	VERTDIS
60	3.49	ROLL	2.99	ROLL	2.99	ROLL
90	1.64	MSIMAX	1.47	MSIMAX	1.47	MSIMAX
120	0 97	MSIMAX	0 97	MSIMAX	0 97	MSIMAX
150	1.13	MSIMAX	1.13	MSIMAX	1.13	MSIMAX
180	1 21	MSIMAX	1.21	MSIMAX	1.21	MSIMAX

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***** PERCENT TIME OPERABLE DUE TO SHIP MOTIONS IN WAVES AND RELATIVE WIND SPEED *****

Speed : 18.0 knots
Modelling of roll response : EXPONENTIAL
Spectrum : BRETSCHNEIDER
Wave type : LONG CRESTED

Heading (deg)	Weight	Percent Time Operable			
		Motion	Air operations	Motion and air operations	Motion given air operations
0.0	0.083	81.6	100.0	81.6	81.6
30.0	0.167	80.9	100.0	80.9	80.9
60.0	0.167	75.3	100.0	75.3	75.3
90.0	0.167	52.7	99.7	52.7	52.9
120.0	0.167	28.2	98.8	28.2	28.5
150.0	0.167	33.2	97.1	33.2	34.2
180.0	0.083	36.0	96.3	36.0	37.4

Weighted Operabilities (per cent) for
Motion criteria : 54.8
Air operations criteria : 98.9
Air operations and motion criteria : 54.8
Motion criteria given air operations : 55.2

***** PERCENT TIME OPERABLE FOR ALL SPEEDS DUE TO SHIP MOTIONS RELATIVE WIND SPEED *****

Modelling of roll response : EXPONENTIAL
Spectrum : BRETSCHNEIDER
Wave type : LONG CRESTED

Speed (kt)	Weight	Percent Time Operable		
		Motion	Air operations	Motion and air operations
18.0	1.000	54.8	98.9	54.8

Weighted Operabilities (per cent) for
Motion criteria : 54.8
Air operations criteria : 98.9
Air operations and motion criteria : 54.8

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Annex D
Locations for Wave Climate Data

SHIPOP2 can read wave data for the Canadian Atlantic, North Atlantic, and North Pacific operational areas.

D.1 Canadian Atlantic

Wave data for the Canadian Atlantic are from Reference 4 and are for annual conditions. Figure D.1 shows the geographical areas for the Canadian Atlantic and Table D.1 gives nominal locations. Table D.2 gives wave and wind climate parameters for the different areas.

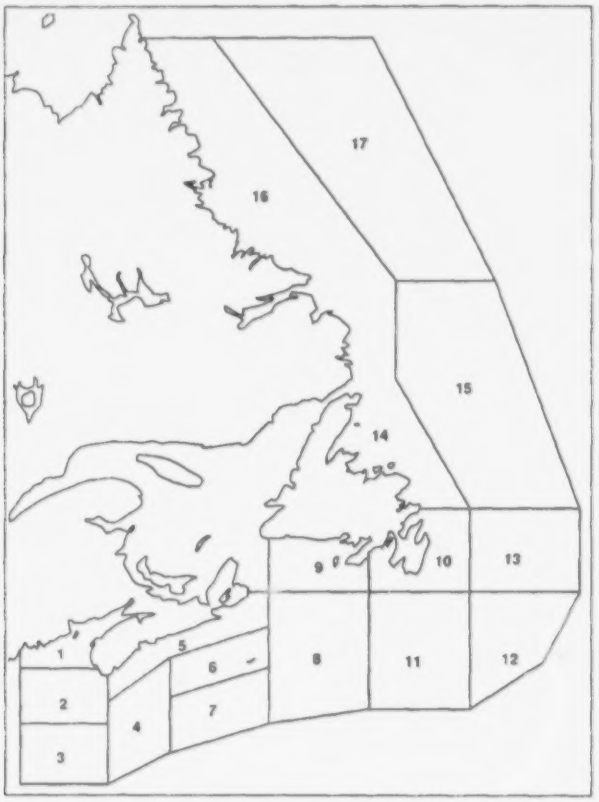

Figure D.1: *Canadian Atlantic Operational Areas (from Reference 4)*

***Table D.1:** Nominal Locations for Canadian Atlantic Wave Data*

	Area	Latitude (deg N)	Longitude (deg, +East)
1	Bay of Fundy	44	-67
2	Lurcher/Brown's Bank	43	-67
3	Georges Bank	41	-67
4	West Scotian Slope	42	-64
5	Nova Scotian Slope	44	-63
6	Sable	44	-61
7	East Scotian Slope	42	-61
8	Banquereau/Laurentian Fan	44	-57
9	South West Coast	47	-57
10	South East Coast	47	-52
11	South Western Grand Banks	44	-53
12	South Eastern Grand Banks	44	-49
13	Northern Grand Banks	47	-49
14	North East Coast	51	-54
15	Belle Isle/Funk Island Banks	52	-50
16	Labrador Coast	56	-59
17	Labrador Sea	57	-55

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Table D.2: *Wave and Wind Climate Parameters for Canadian Atlantic*

		Wave Parameters		Wind Parameters	
	Area	$H_{s,50}$ (m)	$H_{s,90}$ (m)	B_w (kts/m)	C_w (kts)
1	Bay of Fundy	0.58	1.47	5.47	5.40
2	Lurcher/Brown's Bank	1.54	3.44	4.76	5.82
3	Georges Bank	1.84	3.83	4.75	5.24
4	West Scotian Slope	1.83	3.73	4.79	5.34
5	Nova Scotian Slope	1.13	2.42	5.26	5.83
6	Sable	1.68	3.65	4.86	5.04
7	East Scotian Slope	2.02	4.06	4.98	4.37
8	Banquereau/Laurentian Fan	2.00	4.40	4.33	5.58
9	South West Coast	2.24	4.33	4.97	5.15
10	South East Coast	1.82	3.65	4.71	4.27
11	South Western Grand Banks	2.87	5.08	4.41	4.30
12	South Eastern Grand Banks	2.82	5.00	3.76	5.63
13	Northern Grand Banks	2.56	4.87	4.41	4.79
14	North East Coast	2.32	4.33	5.13	3.42
15	Belle Isle/Funk Island Banks	2.89	5.13	4.49	4.67
16	Labrador Coast	1.65	3.57	4.64	6.21
17	Labrador Sea	2.38	4.56	4.51	5.20
	General North Atlantic (Annual)	1.97	5.10	3.54	6.69
	General North Atlantic (Winter)	2.93	6.62	3.76	5.66

D.2 North Atlantic

Figure D.2 shows wave climate grid points for the North Atlantic, with Table D.3 giving the locations in tabular format.

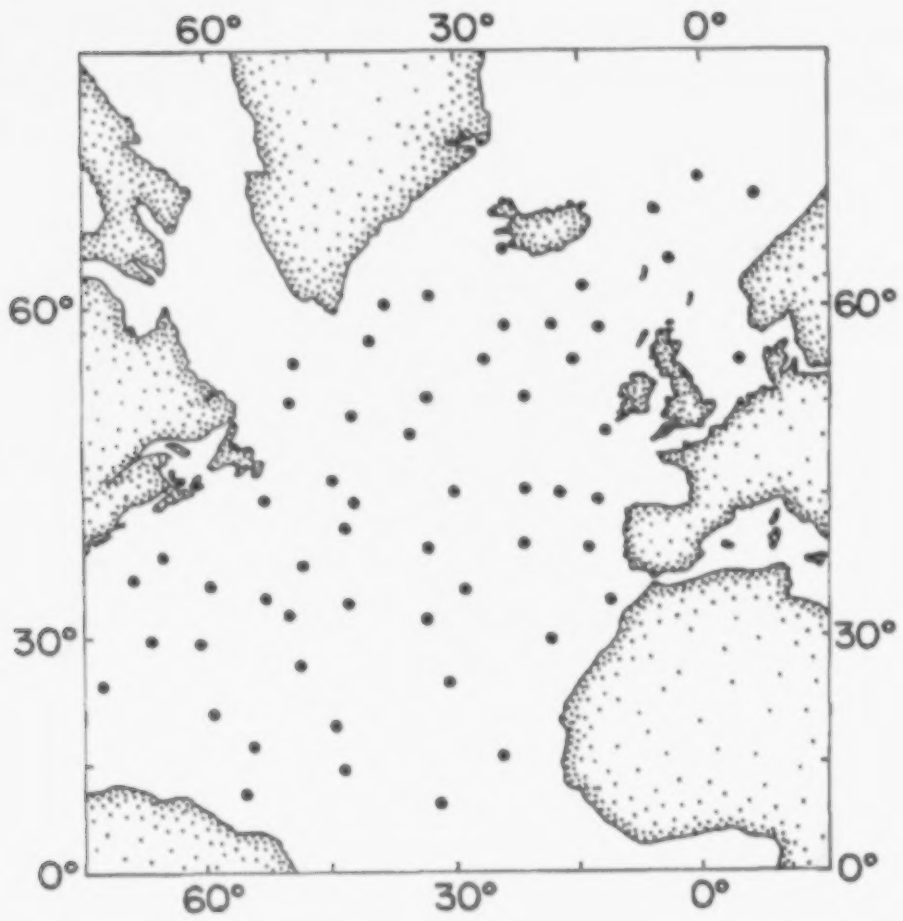

Figure D.2: *Wave Climate Grid Points for the North Atlantic*

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Table D.3: *Wave Climate Locations for the North Atlantic*

Grid Point	Sub Point	Latitude (degrees N)	Longitude (degrees)
38	3	67.69	-0.43
37	3	66.60	6.77
62	3	65.69	-5.85
87	3	63.78	-24.15
84	3	62.85	-3.92
107	3	61.10	-14.64
110	3	60.70	-33.12
111	3	60.05	-38.74
129	3	58.60	-24.02
128	3	58.58	-18.17
127	3	58.29	-12.30
132	3	57.21	-40.26
149	3	55.87	-26.65
124	3	55.87	4.39
147	3	55.80	-15.75
134	3	55.40	-49.35
169	3	52.75	-33.77
304	2	52.61	-49.92
171	3	51.55	-42.67
184	3	50.58	-21.47
182	3	50.02	-11.74
187	3	49.95	-35.40

Table D.3 (cont.) Wave Climate Locations for the North Atlantic

Grid Point	Sub Point	Latitude (degrees N)	Longitude (degrees)
279	2	46.19	-44.89
216	3	45.20	-21.65
218	3	45.10	-30.15
215	3	45.00	-17.28
277	2	44.81	-53.06
214	3	44.64	-12.91
269	2	44.05	-42.07
257	2	41.35	-43.29
244	3	39.91	-21.79
247	2	39.79	-33.23
242	3	39.33	-13.87
263	2	38.77	-65.14
243	2	37.88	-48.22
261	2	36.13	-71.81
240	2	35.13	-59.26
220	2	34.96	-29.00
228	2	34.10	-52.86
265	3	33.75	-11.05
216	2	33.40	-42.98
203	2	32.00	-33.67
214	2	31.95	-50.16
224	2	29.75	-66.53
287	3	29.67	-18.68

Table D.3 (cont.) Wave Climate Locations for the North Atlantic

Grid Point	Sub Point	Latitude (degrees N)	Longitude (degrees)
211	2	29.02	-60.53
182	2	26.69	-48.50
151	2	24.45	-30.94
207	2	24.23	-72.80
161	2	20.84	-59.11
127	2	19.20	-44.70
124	2	16.69	-54.18
69	2	15.45	-24.32
139	2	14.74	-68.37
85	2	14.08	-43.45
81	2	10.82	-55.52
18	2	9.18	-31.93

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D.3 North Pacific

Figure D.3 shows wave climate grid points for the North Pacific, with Table D.4 giving the locations in tabular format.

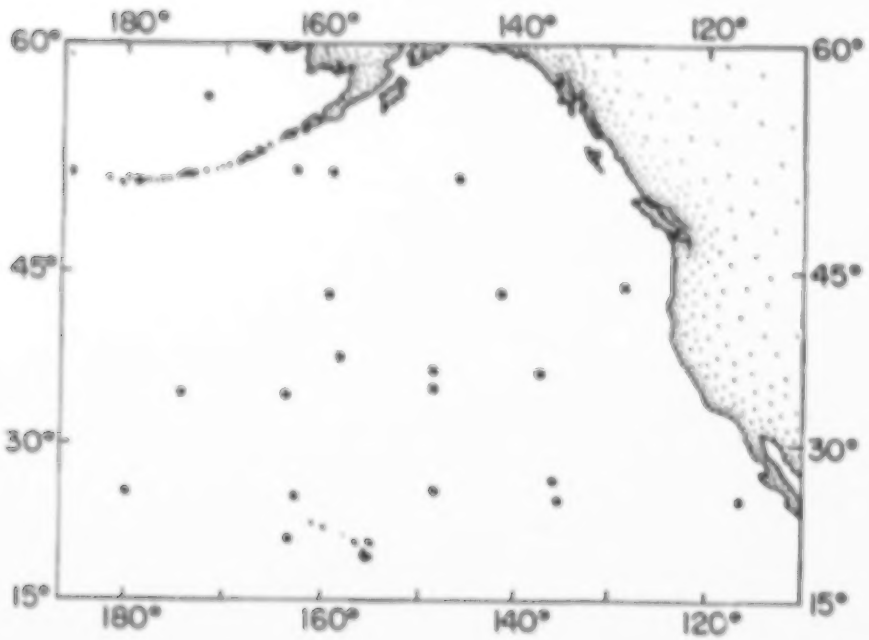

Figure D.3: Wave Climate Grid Points for the North Pacific

Table D.4: Wave Climate Locations for the North Pacific

Grid Point	Sub Point	Latitude (degrees N)	Longitude (degrees)
121	3	56.38	-171.71
28	3	51.35	162.52
124	3	51.31	-158.82
164	3	50.89	-145.65
56	3	50.03	-178.91
202	3	43.73	-128.73
148	3	43.17	-141.43
93	2	42.81	159.01
39	3	37.52	-158.01
294	1	36.32	148.51
188	3	36.16	-127.36
88	3	34.90	-145.58
85	2	34.48	-174.21
152	2	34.16	163.78
239	1	26.51	135.84
255	1	26.02	148.20
165	2	25.19	-179.77
102	2	24.78	-162.46
93	3	24.58	-135.65
121	4	24.25	-116.34
233	2	20.60	163.06

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Annex E
User Input Wave Scattergram Files

SHIPOP2 can read wave scattergram files prepared by the program user. These files can be prepared from sources such as BMT Global Wave Statistics [5]. The SHIPOP2 wave scattergram format is the same as for the capsize risk software described in Reference 14.

When preparing a wave scattergram file, it is important to note that SHIPOP2 requires the file to have peak wave periods. Many data sources such as BMT Global Wave Statistics use zero-crossing period for presenting wave statistics. The following equation can be used to obtain peak wave period T_p from zero-crossing period T_z:

$$T_p = 1.408\, T_z \tag{E.1}$$

E.1 Format of User Input Wave Scattergram Files

Record (1), Description
DESCUSERWAVE (char*80)

DESCUSERWAVE File description (80 character max).

Record (2), Wave Height Parameters and Number of Observations
NHSUSER, HSINCUSER, SUMOBSIN (1 integer, 2 reals)

NHSUSER Number of wave height ranges (Maximum 48).

HSINCUSER Significant wave height increment (m). The increment is typically equal to 0.5 m or 1.0 m.

SUMOBSIN Sum of observations of wave scattergram. The sum is typically 1.0 for a normalized scattergram, or greater than 1,000 when scattergram entries are actual numbers of observations.

Record (3), Number of Peak Wave Periods
NTP (1 integer)

NTP Number of peak wave periods (Maximum 15).

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Record (4), Peak Wave Periods
TP(J) (NTP reals)

TP(J) Array of nominal peak wave periods (s).

Next NHSUSER Records, Lower Value of Significant Wave Height and Joint Observations of Significant Wave Height and Peak Wave Period
HSLOWER, OBSHSTP(I,J) (1 real, NTP reals)

HSLOWER Lower limit of significant wave height range for observations. This value must be set to (I-1)*HSINCUSER, where I is the wave height range index.

OBSHSTP(I,J) Number of observations for wave height range I and nominal peak wave period TP(J).

Note: SHIPOP2 checks to ensure that the sum of all OBSHSTP(I,J) values is equal to SUMOBSIN from Record (2).

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E.2 Example User Input Wave Scattergram File

The following input wave scattergram file is based on data for the North Atlantic presented in Reference 3. The data from Reference 3 has been modified to provide a scattergram with a wave height interval of 0.5 m.

```
North Atlantic Annual Public Domain Data, Shipop2 scattergram format
 40   0.5      130339 0
     15
          3.20   4.50   6.30   7.50   8.50   9.70  10.90  12.40  13.90  15.00  16.40  18.00  20.00  22.50  25.70
  0.00 270.5  170.5   2744   2811   1946 2430.5 1333.5   1306    590  660.5    296  106.5     26      2      0
  0.50 270.5  170.5   2744   2811   1946 2430.5 1333.5   1306    590  660.5    296  106.5     26      2      0
  1.00      0  144.5 1964.5 3315.5 2737.5 2680.5 1823.5   1714  808.5  853.5  472.5  284.5     82      5      0
  1.50      0  144.5 1964.5 3315.5 2737.5 2680.5 1823.5   1714  808.5  853.5  472.5  284.5     82      5      0
  2.00      0      0   14.5   1075 2750.5 2847.5 1914.5   1484    799  633.5    390  210.5     62    1.5      0
  2.50      0      0   14.5   1075 2750.5 2847.5 1914.5   1484    799  633.5    390  210.5     62    1.5      0
  3.00      0      0      0    2.5    411   2291 1936.5 1696.5  728.5    549  311.5    175   48.5      3      0
  3.50      0      0      0    2.5    411   2291 1936.5 1696.5  728.5    549  311.5    175   48.5      3      0
  4.00      0      0      0      0    6.5   306.5 1557.5 1690.5  646.5    504    278    158   37.5      6      0
  4.50      0      0      0      0    6.5   306.5 1557.5 1690.5  646.5    504    278    158   37.5      6      0
  5.00      0      0      0      0      0      11   315.5   1507  631.5  496.5  233.5    154     24    2.5      0
  5.50      0      0      0      0      0      11   315.5   1507  631.5  496.5  233.5    154     24    2.5      0
  6.00      0      0      0      0      0     0.5    13.5    668  551.5    467  214.5  143.5     20      0      0
  6.50      0      0      0      0      0     0.5    13.5    668  551.5    467  214.5  143.5     20      0      0
  7.00      0      0      0      0      0      0       0  114.5    361    389  173.5    115     14      0      3
  7.50      0      0      0      0      0      0       0  114.5    361    389  173.5    115     14      0      3
  8.00      0      0      0      0      0    0.5       0      8    109  299.5    155    100   15.5      0    3.5
  8.50      0      0      0      0      0    0.5       0      8    109  299.5    155    100   15.5      0    3.5
  9.00      0      0      0      0      0      0       0      1     13   93.5    158   81.5     10      1    0.5
  9.50      0      0      0      0      0      0       0      1     13   93.5    158   81.5     10      1    0.5
 10.00      0      0      0      0      0      0       0      0    0.5   20.5    101     53   10.5    0.5      0
 10.50      0      0      0      0      0      0       0      0    0.5   20.5    101     53   10.5    0.5      0
 11.00      0      0      0      0      0      0       0      0      0    3.5   33.5   47.5    7.5      0    0.5
 11.50      0      0      0      0      0      0       0      0      0    3.5   33.5   47.5    7.5      0    0.5
 12.00      0      0      0      0      0      0       0      0      0      0   6.75  28.75   8.75      0      0
 12.50      0      0      0      0      0      0       0      0      0      0   6.75  28.75   8.75      0      0
 13.00      0      0      0      0      0      0       0      0      0      0   6.75  28.75   8.75      0      0
 13.50      0      0      0      0      0      0       0      0      0      0   6.75  28.75   8.75      0      0
 14.00      0      0      0      0      0      0       0      0      0      0      0    6.5    6.5   0.75   0.25
 14.50      0      0      0      0      0      0       0      0      0      0      0    6.5    6.5   0.75   0.25
 15.00      0      0      0      0      0      0       0      0      0      0      0    6.5    6.5   0.75   0.25
 15.50      0      0      0      0      0      0       0      0      0      0      0    6.5    6.5   0.75   0.25
 16.00      0      0      0      0      0      0       0      0      0      0      0      0   1.25   1.25      0
 16.50      0      0      0      0      0      0       0      0      0      0      0      0   1.25   1.25      0
 17.00      0      0      0      0      0      0       0      0      0      0      0      0   1.25   1.25      0
 17.50      0      0      0      0      0      0       0      0      0      0      0      0   1.25   1.25      0
 18.00      0      0      0      0      0      0       0      0      0      0      0      0      0      0   0.25
 18.50      0      0      0      0      0      0       0      0      0      0      0      0      0      0   0.25
 19.00      0      0      0      0      0      0       0      0      0      0      0      0      0      0   0.25
 19.50      0      0      0      0      0      0       0      0      0      0      0      0      0      0   0.25
```

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SHIPOP2 is an updated version of DREA's program for predicting ship operability in waves and wind. Given limiting motion and aircraft operability criteria, SHIPOP2 can compute limiting conditions for ship operability and percent time operable for a specified wave climate. SHIPOP2 is compatible with SHIPMO7, the latest version of DREA's ship motion program. New operability criteria include motion sickness incidence and the effects of ship motions on clearances between ship fixtures and projectiles launched from the ship. To increase the applicability and potential program user base, SHIPOP2 can read public domain wave climate data files and custom wave scattergram files prepared by the program user.

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